

431-ICD-000118

Revision -

Effective Date: To be added upon Release

Expiration Date: To be added upon Release

DRAFT v1.1

Robotic Lunar Exploration Program Lunar Reconnaissance Orbiter (LRO)

LRO-to-CRaTER Thermal Interface Control Document (TICD)

05/16/2005



**Goddard Space Flight Center
Greenbelt, Maryland**

**National Aeronautics and
Space Administration**

CHECK WITH RLEP DATABASE AT:
<https://lunarngin.gsfc.nasa.gov>
TO VERIFY THAT THIS IS THE CORRECT VERSION PRIOR TO USE.

CM FOREWORD

This document is a Robotic Lunar Exploration Program (RLEP) Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the RLEP CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

Questions or comments concerning this document should be addressed to:

RLEP Configuration Management Office
Mail Stop 431
Goddard Space Flight Center
Greenbelt, Maryland 20771

SIGNATURE PAGE***Prepared by:***

William Chang LRO Thermal Systems Engineer Edge Space Systems, Inc.	Date

Reviewed by:

Joanne Baker LRO I&T Manager GSFC/Code 568	Date	Mike Pryzby LRO Spacecraft Systems Manager Swales Aerospace	Date

Approved by:

Craig Tooley LRO Project Manager GSFC/Code 430	Date	Charles Baker LRO Lead Thermal Systems Engineer GSFC/Code 545	Date

Concurred by:

Prof. Harlan E. Spence Boston University CRaTER Principal Investigator	Date	Arlin Bartels RLEP Payload Systems Manager GSFC/Code 430	Date

ROBOTIC LUNAR EXPLORATION PROGRAM

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED

CHECK WITH RLEP DATABASE AT:
<https://lunarngin.gsfc.nasa.gov>
TO VERIFY THAT THIS IS THE CORRECT VERSION PRIOR TO USE.

List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date

TABLE OF CONTENTS

	<u>Page</u>
<u>1.0 INTRODUCTION</u>	1-1
<u>1.1 GENERAL</u>	1-1
<u>1.2 PURPOSE</u>	1-1
<u>1.3 APPROVAL</u>	1-1
<u>1.4 RESPONSIBILITY</u>	1-1
<u>1.5 APPLICABLE DOCUMENTS</u>	1-2
<u>2.0 LRO REFERENCE COORDINATE SYSTEM</u>	2-3
<u>3.0 THERMAL INTERFACES</u>	3-1
<u>3.1 INTERFACE DEFINITIONS</u>	3-1
<u>3.2 INSTRUMENT REFERENCE LOCATIONS</u>	3-1
<u>3.3 INSTRUMENT TEMPERATURE LIMITS</u>	3-1
<u>3.4 SPECIFICATION OF INSTRUMENT-SIDE TEMPERATURES</u>	3-1
<u>3.5 ADDITIONAL THERMAL INFORMATION</u>	3-2
<u>4.0 SPACECRAFT THERMAL DESIGN CONCEPT {TBR GSFC:wsc}</u>	4-3
<u>5.0 CRaTER THERMAL DESIGN CONCEPT</u>	5-1
<u>5.1 THERMAL COUPLING</u>	5-1
<u>5.1.1 CRaTER-To-Spacecraft Conductive Coupling</u>	5-1
<u>5.1.2 CRaTER-To-Spacecraft Radiative Coupling</u>	5-2
<u>5.1.3 Heat Balance</u>	5-2
<u>5.2 INTERNAL CONTROLS</u>	5-2
<u>5.3 INTERNAL POWER DISSIPATIONS</u>	5-2
<u>5.4 THERMAL CONTROL COATINGS</u>	5-2
<u>5.5 THERMAL BLANKETS</u>	5-2
<u>5.5.1 Venting Requirements</u>	5-2
<u>5.5.2 Grounding Requirements</u>	5-3
<u>5.5.3 Cleanliness Requirements</u>	5-3
<u>5.5.4 Blanket Interface with Spacecraft</u>	5-3
<u>6.0 INTERFACE TEMPERATURE REQUIREMENTS</u>	6-1
<u>6.1 TEMPERATURE RANGE REQUIREMENTS</u>	6-1
<u>6.2 TEMPERATURE RATE-OF-CHANGE REQUIREMENTS</u>	6-1
<u>6.3 TEMPERATURE GRADIENT REQUIREMENTS</u>	6-1
<u>7.0 TEMPERATURE MONITORING</u>	7-2
<u>7.1 CRaTER REFERENCE LOCATIONS</u>	7-2
<u>7.2 EXTERNALLY MOUNTED S/C TEMPERATURE SENSORS</u>	7-2
<u>7.3 INTERNALLY MOUNTED S/C TEMPERATURE SENSORS</u>	7-2
<u>7.4 INSTRUMENT MONITORED TEMPERATURE SENSORS</u>	7-2

7.5	<u>TEMPERATURE LIMITS</u>	7-2
7.6	<u>ADDITIONAL THERMAL INFORMATION</u>	7-3
8.0	<u>HEATERS</u>	8-1
8.1	<u>GENERAL REQUIREMENTS</u>	8-1
8.2	<u>OPERATIONAL HEATERS</u>	8-1
8.3	<u>SURVIVAL HEATERS</u>	8-1
8.4	<u>DECONTAMINATION HEATERS</u>	8-1
9.0	<u>THERMAL MODEL REQUIREMENTS</u>	9-1
9.1	<u>GENERAL REQUIREMENTS</u>	9-1
9.2	<u>ENVIRONMENTAL CONSTANTS</u>	9-1
9.3	<u>THERMAL MODEL FORMATS</u>	9-1
9.4	<u>INSTRUMENT REDUCED THERMAL MODEL REQUIREMENTS</u>	9-1
9.5	<u>THERMAL MODEL DOCUMENTATION</u>	9-2
9.6	<u>ORBITER DELIVERABLES</u>	9-2
	9.6.1 <u>Reduced Orbiter Thermal Models</u>	9-2
	9.6.2 <u>Environmental Heating and Spacecraft Backload Information</u>	9-2
10.0	<u>THERMAL VACUUM TEST CONSIDERATIONS</u>	10-1
10.1	<u>HIGH-VOLTAGE POWER SUPPLIES</u>	10-1
10.2	<u>TEST HEATERS</u>	10-1
10.3	<u>TEST SENSORS</u>	10-1
10.4	<u>GREEN TAG ITEMS</u>	10-1
10.5	<u>RED TAG ITEMS</u>	10-2
	<u>APPENDIX A: ABBREVIATIONS AND ACRONYMS</u>	1

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
Figure 2-1: LRO Reference Coordinate System Definition	2-3
Figure 4-1: LRO Orbiter (Design ‘E’)	4-5
Figure 5-1: CRaTER Instrument	5-1

LIST OF TABLES

<u>Table</u>	<u>Page</u>
Table 1-1: Applicable Documents	1-2
Table 7-1: CRaTER Reference Locations	7-2
Table 7-2: CRaTER Reference Location Temperature Limits	7-3
Table 7-3: CRaTER Critical Node Temperature Limits	7-3

1.0 INTRODUCTION

The Lunar Reconnaissance Orbiter (LRO) is the first mission of the Robotic Lunar Exploration Program (RLEP). The LRO mission objective is to conduct investigations that will be specifically targeted to prepare for and support future human exploration of the Moon. This mission is currently scheduled to launch in October 2008 and is planned to take measurements of the Moon for at least one year.

1.1 GENERAL

This Thermal Interface Control Document (TICD) defines and controls the top level thermal interface between the LRO spacecraft and the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument necessary to manifest, build, test, and successfully fly the LRO mission.

1.2 PURPOSE

The purpose of this TICD is to ensure compatibility between the CRaTER instrument and the LRO spacecraft by:

- a. Defining and controlling the interfaces between the instrument and the spacecraft; and
- b. Defining top level constraints that shall be observed by the instrument and the LRO spacecraft. The top-level requirements are the general requirements that all subsystems must comply with to fly aboard the LRO mission.

1.3 APPROVAL

Approval of this TICD by the Configuration Control Board shall baseline the LRO spacecraft to instrument interfaces.

1.4 RESPONSIBILITY

The Goddard Space Flight Center (GSFC) has the final responsibility for the design of the thermal control system for the LRO spacecraft, its subsystems, and any requirements specifically assigned to LRO in this document.

Boston University (BU) has the final responsibility for the design of the thermal control system for the CRaTER instrument, its subsystems, and any requirements specifically assigned to CRaTER in this document.

CRaTER shall be accompanied by all mechanical, electrical, and thermal GSE necessary to allow for full handling and thermal testing and will be provided by BU.

1.5 APPLICABLE DOCUMENTS

The documents that form a part of this TICD to the extent specified herein are provided in Table 1-1.

Table 1-1: Applicable Documents

DOCUMENT NO.	TITLE
GEVS-SE Rev. A	“General Environmental Verification Specification for STS and ELV Payloads, Subsystems and Components”
431-RQMT-000092	“LRO Thermal Math Model Requirements”
431-SPEC-000091	“LRO General Thermal Subsystem Specification”
431-ICD-00008	“LRO Electrical ICD” {TBR GSFC}
431-ICD-000094	“CRaTER EICD” {TBR GSFC}
431-PLAN-000110	“LRO Contamination Control Plan” {TBR GSFC}
431-ICD-000084	“LRO Instrument Mechanical Interface Control Document” {TBR GSFC}
431-ICD-000085	“CRaTER MICD” {TBR GSFC}
{TBS BU}	CRaTER TID {TBS BU}

2.0 LRO REFERENCE COORDINATE SYSTEM

The LRO mechanical and thermal reference coordinate system is defined in Document 431-ICD-000084 (“LRO Instrument Mechanical Interface Control Document”). Figure 2-1 is a copy of the defined coordinate system. Unless otherwise noted, this document shall refer to the LRO reference coordinate system.

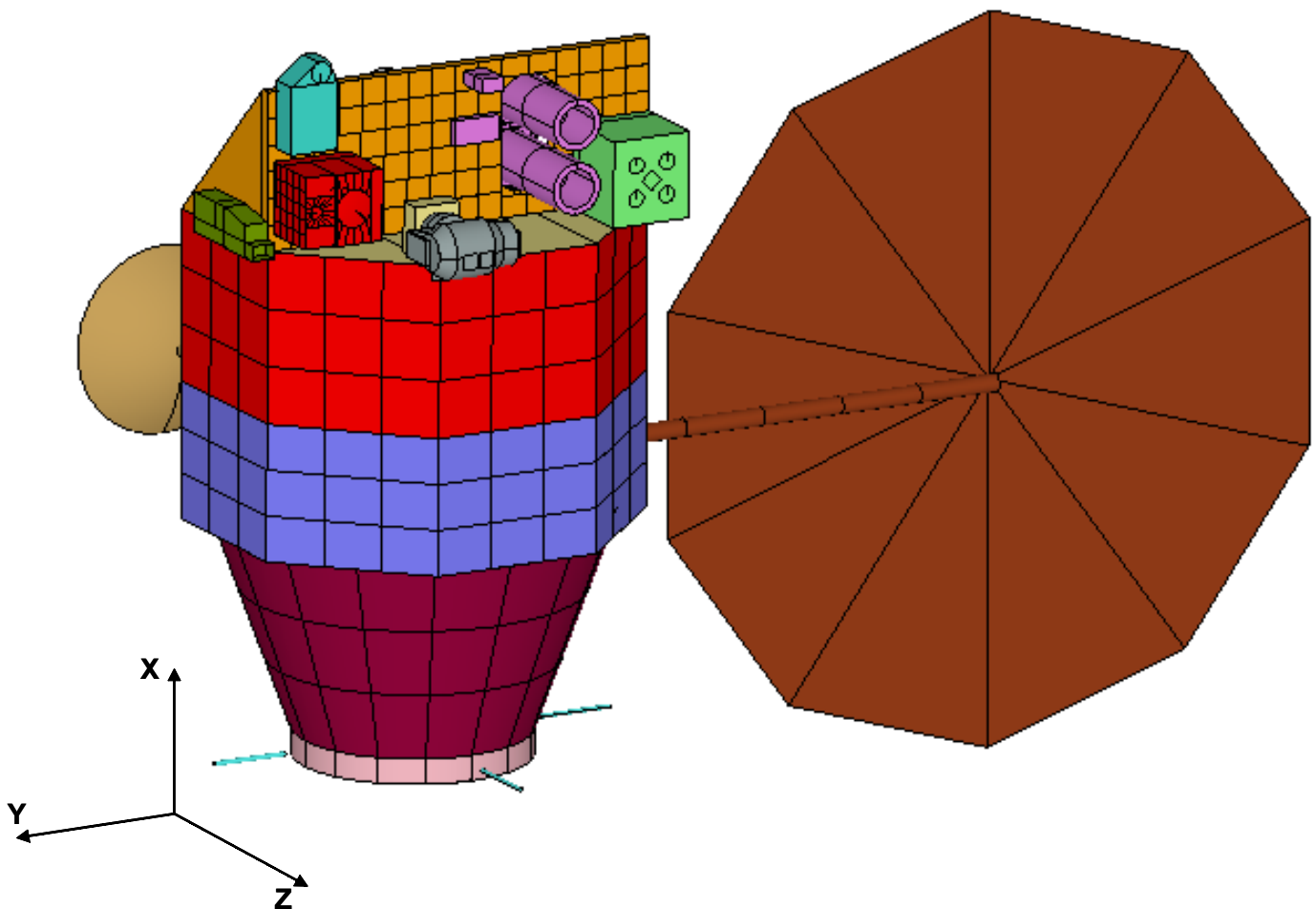


Figure 2-1: LRO Reference Coordinate System Definition

3.0 THERMAL INTERFACES

These requirements apply to all instruments.

3.1 INTERFACE DEFINITIONS

The spacecraft-side interface is defined as the mounting surface on the spacecraft side of the interface.

The instrument-side interface is defined as the mounting surface on the instrument side of the interface.

3.2 INSTRUMENT REFERENCE LOCATIONS

Each Instrument Development Team (IDT) shall choose at least one reference location on each separate instrument assembly (e.g., electronics box, optical component, or detector assembly) at which temperature measurements can validate the thermal design. To support this validation, each location must be equipped with a spacecraft-monitored temperature sensor, be thermally separate from the spacecraft (at least to the degree that heat flow to/from the spacecraft can be quantified) and correspond to a node in the thermal model.

3.3 INSTRUMENT TEMPERATURE LIMITS

BU shall provide flight design, operational, survival, and qualification temperature limits associated with the above reference location(s). Refer to Section 2.1 of Document 431-SPEC-000091 (“LRO General Thermal Subsystem Specification”) for a complete definition of these temperature limit types.

3.4 SPECIFICATION OF INSTRUMENT-SIDE TEMPERATURES

Each IDT shall, in this document:

- a. Provide the reference location(s) on a Thermal Interface Drawing (TID) and a brief description of each location and its significance
- b. Provide temperature limits associated with each reference location per Sections 3.2 and 3.3 of this document
- c. Identify the node in the reduced thermal models delivered to GSFC corresponding to each reference location

3.5 ADDITIONAL THERMAL INFORMATION

For locations in the instrument that have significantly different temperature limits from the reference location, the IDT shall make each such location a node in its thermal model to be delivered to GSFC.

For locations in the instrument that have significantly different temperature limits from the reference location, the IDT shall provide the flight design limit for each node to the LRO Lead Thermal Engineer. No spacecraft-monitored temperature sensors are required for these additional locations; however, it may be advantageous to place instrument monitored temperature sensors at some or all of these locations.

4.0 SPACECRAFT THERMAL DESIGN CONCEPT **{TBR GSFC:WSC}**

The instruments and principal component/subsystems comprising LRO are depicted in Figure 4-1. The configuration shown reflects the design ‘E’ concept. LRO is divided into three (3) major segments plus the Solar Array Assembly (SAA) and High Gain Antenna (HGA). The three segments are the Instrument Module (IM), Avionics Module (AM) and Propulsion Module (PM).

The IM consists of the instrument deck and an optical bench (OB). The instruments are mounted to the OB along with the **{TBD GSFC:wsc}** (IRU). The OB is a 5.08 cm (2.0 in) thick panel with aluminum honeycomb core sandwiched between two **{TBD GSFC:wsc}** cm (**{TBD GSFC:wsc}** in) thick K13C **{TBR GSFC:wsc}** face sheets. The -Z side of the OB serves as a radiating surface. The +Z side of the OB is covered with multi-layered insulation (MLI) having 15-layers **{TBR GSFC:clb}**. The outermost layer of the MLI will be 3-mil Kapton.

The AM is an eight-sided structure consisting of panels mounted to a skeletal frame. Each panel is **{TBD GSFC:wsc}** cm (**{TBD GSFC:wsc}** in) thick with aluminum honeycomb core sandwiched between two **{TBD GSFC:wsc}** cm (**{TBD GSFC:wsc}** in) thick K13C **{TBD GSFC:wsc}** face sheets. The AM houses the Battery, Command and Data Handling (C&DH) box, Propulsion & Deployable Electronics (PDE) box, Power System Electronics (PSE) box, S-Band Transponder and four (4) Reaction Wheel Assemblies (RWA) **{TBD GSFC:wsc}**. The RWAs are mounted on the bottom deck while the remaining avionics boxes are mounted on the inboard face of some of the panels. The outboard faces of these panels serve as radiating surfaces to dissipate the heat rejected by the avionics boxes. The remaining panels are covered with multi-layered insulation (MLI).

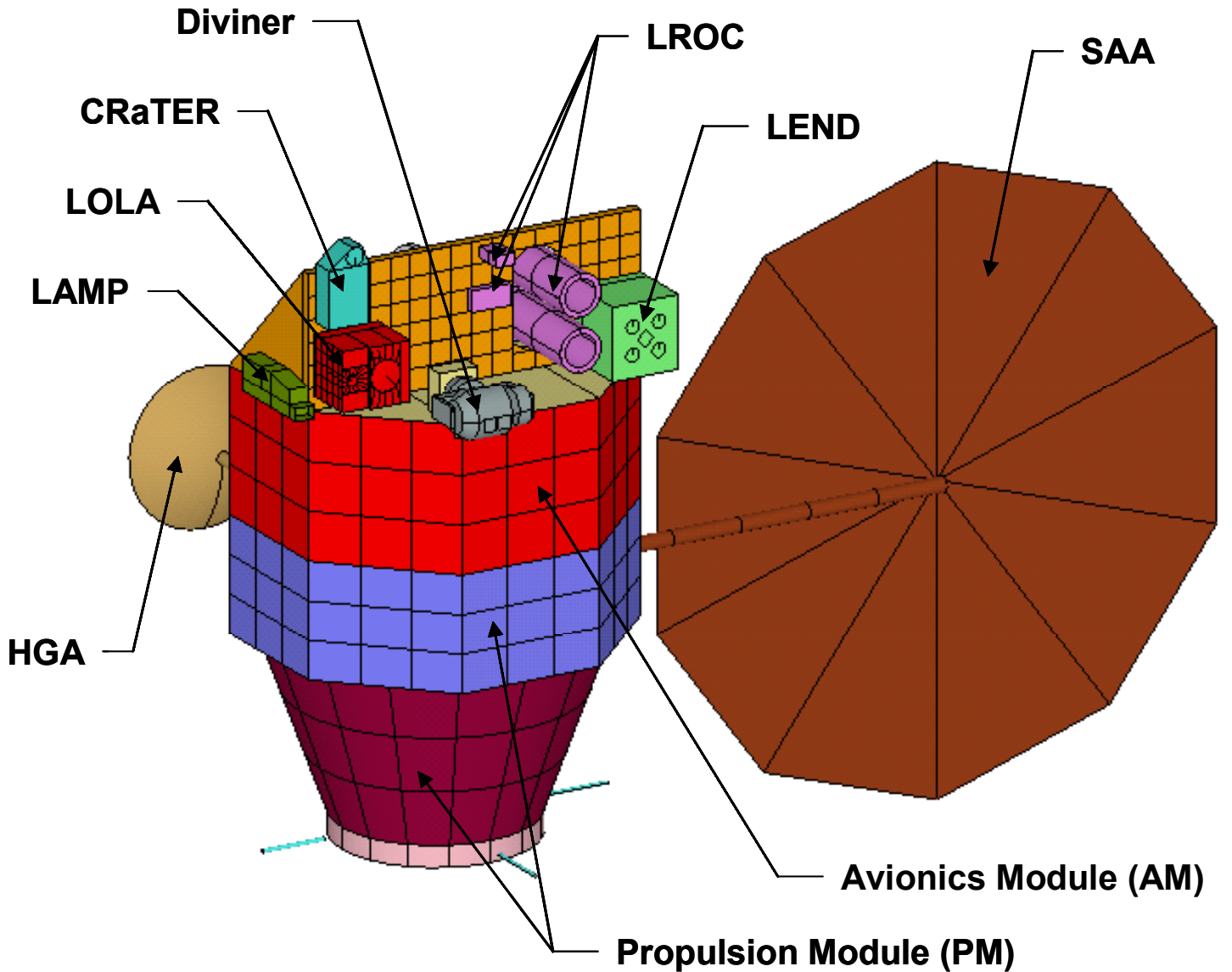


Figure 4-1: LRO Orbiter (Design 'E')

5.0 CRATER THERMAL DESIGN CONCEPT

Provide a brief description of the instrument and thermal design. Provide a picture below.
{TBS BU}

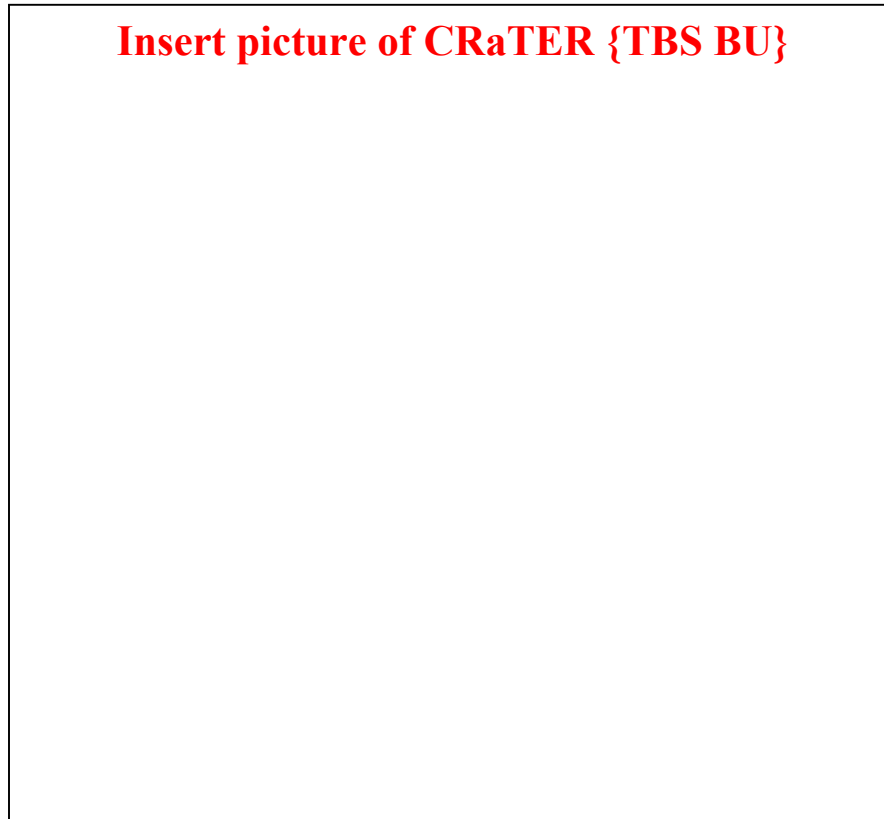


Figure 5-1: CRaTER Instrument

5.1 THERMAL COUPLING

5.1.1 CRaTER-To-Spacecraft Conductive Coupling

The spacecraft shall provide a conductive interface under the footprint of the CRaTER mounting feet *{TBR BU}*.

CRaTER shall conduct no more than *{TBD GSFC:wsc}* W of power either into or out of the spacecraft during operational modes.

CRaTER shall conduct no more than *{TBD GSFC:wsc}* W of power either into or out of the spacecraft while in survival mode.

5.1.2 CRaTER-To-Spacecraft Radiative Coupling

The spacecraft Optical Bench (OB) in the vicinity of CRaTER and directly underneath its footprint shall be covered by MLI. The outer layer of the MLI shall be 3-mil Kapton with an emittance > 0.76 . {TBR GSFC:wsc}.

5.1.3 Heat Balance

The total heat exchange rate (conduction and radiation) either into or out of the spacecraft shall be less than {TBD GSFC:wsc} W for all operational modes.

The total heat exchange rate (conduction and radiation) either into or out of the spacecraft shall be less than {TBD GSFC:wsc} W during survival mode.

5.2 INTERNAL CONTROLS

CRaTER has no internal heaters.

5.3 INTERNAL POWER DISSIPATIONS

Specify minimum and maximum power dissipations and provide power profiles (i.e., mission modes, sunlight vs. eclipse, etc.). {TBS BU}

5.4 THERMAL CONTROL COATINGS

Specify and describe the coatings on all external surfaces that view the spacecraft and/or neighboring instruments/subsystems. Properties for these coatings must be approved by GSFC for use on LRO. {TBS BU}

5.5 THERMAL BLANKETS

BU shall provide and install all MLI that will cover the CRaTER instrument. Blankets shall be 15-layer MLI {TBR BU}. The outermost layer of MLI viewing the spacecraft and neighboring instruments/components will be 3-mil Kapton {TBR BU}. Blanket details are specified in the CRaTER TID {TBD BU}.

5.5.1 Venting Requirements

Blankets shall be adequately vented in accordance with Document 431-SPEC-000091 (“LRO General Thermal Subsystem Specification”).

Blanket venting details for the CRaTER instrument are provided in CRaTER TID {TBS BU}.

5.5.2 Grounding Requirements

Blankets shall be adequately grounded in accordance with Document 431-SPEC-000091 (“LRO General Thermal Subsystem Specification”) and Document 431-ICD-00008 (“LRO Electrical ICD”).

Blanket grounding details for the CRaTER instrument are provided in CRaTER TID **{TBS BU}**.

5.5.3 Cleanliness Requirements

Blankets shall be baked-out and meet cleanliness requirements in accordance with Document 431-PLAN-000110 (“LRO Contamination Control Plan”).

5.5.4 Blanket Interface with Spacecraft

Refer to Document 431-SPEC-000091 (“LRO General Thermal Subsystem Requirements”) for details regarding blanket interface between the spacecraft and the instrument.

6.0 INTERFACE TEMPERATURE REQUIREMENTS

6.1 TEMPERATURE RANGE REQUIREMENTS

The spacecraft has two (2) thermal modes of operation, the operational mode and survival mode. The spacecraft thermal control system (TCS) shall maintain the temperature on the spacecraft-side of the interface within the temperature ranges specified below and in Section 2.3 of Document 431-SPEC-000091 (“LRO General Thermal Subsystem Specification”) {TBR GSFC:wsc}. Where contradictory values are found, the temperature ranges listed below shall take precedence.

- Operational Range: -30°C to +35°C {TBD GSFC:wsc}
- Survival Range: -40°C to +50°C {TBD GSFC:wsc}

The temperature ranges provided are based on CRaTER being powered “ON” in operational mode and powered “OFF” in safe-hold mode.

BU is responsible for meeting all performance requirements for the CRaTER instrument under the specified temperature range during all mission modes.

6.2 TEMPERATURE RATE-OF-CHANGE REQUIREMENTS

CRaTER has no temperature rate-of-change requirements.

6.3 TEMPERATURE GRADIENT REQUIREMENTS

CRaTER has no temperature gradient requirements.

7.0 TEMPERATURE MONITORING

7.1 CRATER REFERENCE LOCATIONS

The spacecraft shall allocate two (2) spacecraft-monitored temperature sensors to the CRaTER instrument to be located on the instrument-side of the interface at their discretion. GSFC is responsible for providing the temperature sensors. The type of sensor used is specified in Document 431-SPEC-000091 (“LRO General Thermal Subsystem Specification”).

A description of sensor locations along with their representative node in the thermal model is provided in Table 7-1. Temperature limits for these locations are provided in Section 7-5 {TBR GSFC:wsc} of this document. Refer to CRaTER TID {TBD BU} for exact locations.

Table 7-1: CRaTER Reference Locations

#	DESCRIPTION	INT. / EXT.	SUBMODEL	NODE #
1	{TBS BU}	Internal		
2	{TBS BU}	External		

7.2 EXTERNALLY MOUNTED S/C TEMPERATURE SENSORS

GSFC is responsible for installing all externally mounted spacecraft-monitored temperature sensors specified in the CRaTER TID {TBR BU}.

7.3 INTERNALLY MOUNTED S/C TEMPERATURE SENSORS

BU is responsible for installing all internally mounted spacecraft-monitored temperature sensors specified in the CRaTER TID {TBR BU}.

7.4 INSTRUMENT MONITORED TEMPERATURE SENSORS

BU is responsible for providing and installing all temperature sensors that will be monitored by the instrument. The locations of these sensors are specified in the CRaTER TID {TBR BU}.

7.5 TEMPERATURE LIMITS

During all mission operational modes when the instrument is powered “ON”, GSFC shall be responsible for maintaining the instrument within its operational temperature limits via the spacecraft thermal control system.

During all mission safe-hold modes when the instrument is powered “OFF”, GSFC shall be responsible for maintaining the instrument within its survival temperature limits via the spacecraft thermal control system. CRaTER shall survive without damage or permanent performance degradation if powered “ON” anywhere within the survival temperature range.

A list of operational and survival temperature limits, along with flight design and qualification limits, is provided in Table 7-2.

Table 7-2: CRaTER Reference Location Temperature Limits

#	DESCRIPTION	NODE#	MIN/MAX TEMP. LIMITS (°C)			
			OPER.	SURV.	DESIGN	QUAL.
1	{TBS BU}					
2	{TBS BU}					

7.6 ADDITIONAL THERMAL INFORMATION

In addition to the reference locations provided above, there are {TBD BU} critical components that shall be monitored by the instrument and/or tracked in the thermal models. A listing of the temperature limits and their representative nodes in the thermal model is provided in Table 7-3.

Table 7-3: CRaTER Critical Node Temperature Limits

#	DESCRIPTION	NODE#	MIN/MAX TEMP. LIMITS (°C)			
			OPER.	SURV.	DESIGN	QUAL.
1	{TBS BU}					
2	{TBS BU}					

8.0 HEATERS

8.1 GENERAL REQUIREMENTS

Sizing of operational and survival heater capacity shall be based on 70% duty cycle (43% margin) at 24V {TBR GSFC:clb} bus voltage and cold case thermal conditions. Heater elements must be capable of operating over the voltage range of $28 \pm 7V$.

Each instrument will provide space for mounting heaters, thermostats and temperature sensors.

Watt densities of the operational and survival heaters shall be appropriate for the type of heater and bonding method. Watt densities (at the maximum voltage) above 0.16 W/cm^2 (1.0 W/in^2) shall be discussed with the GSFC LRO Lead Thermal Engineer and may require (if a Kapton heater) bonding with Stycast 2850FT and aluminum over-taping up to 1.24 W/cm^2 (8.0 W/in^2).

8.2 OPERATIONAL HEATERS

GSFC shall provide any operational heaters, cabling and thermostats that are necessary. Any such heaters and associated hardware may be mounted either on the spacecraft, the CRaTER, or both. The placement of heaters shall be negotiated between GSFC and BU. GSFC shall install and the spacecraft shall control any such operational heaters, as needed, to maintain the temperatures on the spacecraft-side of the mounting interface within the operational temperature range specified in Section 6.1 {TBR GSFC:wsc} of this document.

8.3 SURVIVAL HEATERS

GSFC shall provide any survival heaters, cabling and thermostats that are necessary. Any such heaters and associated hardware may be mounted either on the spacecraft, the CRaTER, or both. The placement of heaters shall be negotiated between GSFC and BU. GSFC shall install and the spacecraft shall control any such survival heaters, as needed, to maintain the temperatures on the spacecraft-side of the mounting interface within the survival temperature range specified in Section 6.1 {TBR GSFC:wsc} of this document.

8.4 DECONTAMINATION HEATERS

CRaTER has no decontamination heaters.

9.0 THERMAL MODEL REQUIREMENTS

9.1 GENERAL REQUIREMENTS

Each IDT shall deliver reduced thermal models and temperature predictions for relevant mission modes to GSFC. These models will be integrated with the spacecraft model that is used to generate flight predicted temperatures for various mission phases.

GSFC shall deliver either reduced thermal models of the Orbiter or environmental heating and spacecraft backload information to each IDT. Reduced thermal models allow each IDT to substitute their detailed model for the reduced representation of the instrument and perform any analyses deemed necessary. Environmental heating and spacecraft backload information will be based on the worst hot/cold operational and safe-hold cases for the spacecraft. Each IDT should bear in mind that the worst hot/cold case for the spacecraft may not necessarily be the worst hot/cold case for their instrument.

9.2 ENVIRONMENTAL CONSTANTS

Each IDT shall utilize the environmental constants specified in Document 431-SPEC-000091 (“LRO General Thermal Subsystem Specification”).

9.3 THERMAL MODEL FORMATS

Each IDT shall deliver their geometry and thermal math models in the format specified in Document 431-RQMT-000092 (“LRO Thermal Math Model Requirements”). Said document provides specific requirements for model formats, naming conventions, etc. to facilitate integration of instrument models with the spacecraft model and shall be strictly adhered to.

9.4 INSTRUMENT REDUCED THERMAL MODEL REQUIREMENTS

The delivered thermal models shall be a reduced version of the detailed thermal models. The reduced geometry math model (RGMM) and reduced thermal math model (RTMM) shall include an adequate level of detail to predict, under worst case hot and cold conditions, all critical temperatures, including those that drive operational and survival temperature limits and heater power where applicable. Worst case conditions will include variations in season, orbit selection, orbital time, and environmental flux parameters (seasonal and spatial) and a rational combination of the effects of design tolerances, fabrication uncertainties, and degradation due to aging.

The RGMM and RTMM shall be correlated to the detailed models within $\pm 2^{\circ}\text{C}$ for critical nodes and components and shall include a representative node(s) at the reference location(s).

BU shall deliver an RGMM having no more than 50 surfaces and an RTMM having no more than 75 thermal nodes.

9.5 THERMAL MODEL DOCUMENTATION

The RGMMs and RTMMs delivered to GSFC shall be accompanied by appropriate model documentation as specified in Document 431-RQMT-000092 (“LRO Thermal Math Model Requirements”).

9.6 ORBITER DELIVERABLES

GSFC shall deliver either a set of reduced geometry and thermal models of the Orbiter or environmental heating and spacecraft backload information to each IDT.

9.6.1 Reduced Orbiter Thermal Models

For those vendors utilizing the TSS and SINDA software tools, GSFC shall provide an RGMM and RTMM of the complete Orbiter. Each vendor shall delete the representation of their instrument/component and replace it with their own detailed versions of the same. The models may then be used to perform any thermal analyses deemed necessary by the vendor.

The RGMM and RTMM shall be accompanied by model documentation per Document 431-RQMT-000092 (“LRO Thermal Math Model Requirements”).

9.6.2 Environmental Heating and Spacecraft Backload Information

For those vendors utilizing thermal software tools other than TSS and SINDA, GSFC shall provide environmental and spacecraft backload information. Backload information will be mapped onto the external surfaces/nodes of the reduced thermal models that were provided to GSFC. In the absence of delivered models, backload information will be mapped onto reduced models developed by GSFC based on information that was available.

Backload information will be based on Orbiter hot, cold, and survival cases only. Note that the Orbiter hot and cold cases may not necessarily be the hot and cold cases for your particular instrument.

Backload information will be provided for each surface/node on a per unit area basis. It will be the responsibility of each vendor to map the backload data onto their detailed models.

10.0 THERMAL VACUUM TEST CONSIDERATIONS

The purpose of this section is to encourage vendors to anticipate, as much as possible, any special requirements and/or needs that may arise during Orbiter Thermal Vacuum (TVAC) testing. These may include, but not necessarily limited to, such items as test heaters or internal test temperature sensors as described below.

10.1 HIGH-VOLTAGE POWER SUPPLIES

CRaTER has no high voltage power supplies.

10.2 TEST HEATERS

During Orbiter TVAC testing, the test configuration of the Orbiter in the vicinity of each instrument may not be flight like due to placement of heater panels and cold plates to facilitate testing that will obviously not be present during flight. The primary objective during Orbiter TVAC will be to thermally test the LRO spacecraft. Consequently, test conditions may dictate that the effective sink temperature for some instruments may be colder than during the mission. Each IDT shall anticipate, to the extent possible, such possibilities and provide test heaters to keep the instrument within survival limits.

In such cases, the IDTs shall be responsible for providing their own test heaters, cabling and means of control. Any such heaters and associated hardware need not be flight qualified and shall be mounted on the instrument, not the spacecraft. The IDTs shall install and control any such test heaters, as needed, to maintain the safety of the instrument during TVAC.

Heater leads should be properly labeled and be of sufficient length to allow connection to test chamber heater harnesses.

10.3 TEST SENSORS

Where there is a desire to monitor temperatures of internal components during TVAC, each IDT shall deliver their instruments with the temperature sensor already installed. Temperature sensors used only during testing need not be flight qualified.

Temperature sensor leads should be properly labeled and be of sufficient length to allow connection to test chamber wire harnesses.

10.4 GREEN TAG ITEMS

Green tag items are those that must be installed prior to flight or environmental testing.

CRaTER has no green tag items.

10.5 RED TAG ITEMS

Red tag items are those that must be removed prior to flight or environmental testing.

CRaTER has no red tag items.

APPENDIX A: ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	DEFINITION
AM	Avionics Module
BU	Boston University
CBE	Current Best Estimate
C&DH	Command and Data Handling
CRaTER	Cosmic Ray Telescope for the Effects of Radiation
Diviner	Diviner Lunar Radiometer Experiment
EICD	Electrical Interface Control Document
ESS	Edge Space Systems, Inc.
FAC	Scale factor card used in SINDA
FOV	Field Of View
GMM	Geometric Math Model
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
ICD	Interface Control Document
IDT	Instrument Development Team
I/F	Interface
IM	Instrument Module
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LOLA	Lunar Orbiter Laser Altimeter
LROC	Lunar Reconnaissance Orbiter Camera
LRO	Lunar Reconnaissance Orbiter
MICD	Mechanical Interface Control Document
MID	Mechanical Interface Drawing
MLI	Multi-Layer Insulation
NAC	Narrow Angle Component
NASA	National Aeronautics and Space Administration
OB	Optical Bench
PDE	Propulsion and Deployables Electronics
PSE	Power Systems Electronics
PM	Propulsion Module
RGMM	Reduced Geometric Math Model
RLEP	Robotic Lunar Exploration Program
RTMM	Reduced Thermal Math Model
RWA	Reaction Wheel Assembly
SAA	Solar Array Assembly
SAHGA	Solar Array/High Gain Antenna
S/C	Spacecraft
SCS	Sequencing & Compressor System

SINDA	Systems Improved Numerical Differencing Analyzer
TBD	To Be Determined
TBR	To Be Reviewed
TBS	To Be Supplied
TCS	Thermal Control System
TICD	Thermal Interface Control Document
TID	Thermal Interface Drawing
TMM	Thermal Math Model
TSS	Thermal Synthesizer System
VDA	Vapor Deposited Aluminum
VDG	Vapor Deposited Gold
WAC	Wide Angle Component