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**DRAFT**

**Robotic Lunar Exploration Program  
Lunar Reconnaissance Orbiter**

**Thermal System Specification**

**May 5, 2005**



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**Goddard Space Flight Center  
Greenbelt, Maryland**

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**National Aeronautics and  
Space Administration**

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Questions or comments concerning this document should be addressed to:

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**LUNAR RECONNAISSANCE ORBITER PROJECT**

**DOCUMENT CHANGE RECORD**

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REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
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## List of TBDs/TBRs

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1	Page 1-1, Section 1.4.1	Provide document numbers to replace TBDs		
2	Page 1-2, Section 1.4.2	Provide document number to replace TBD		
3	Page 2-2, Section 2.2	Provide document number to replace TBD		
4	Page 2-2 & 2-4, Table 2-2	Verify values and update. <b>I need to update before release.</b>		
5	Page 2-5, Table 2-2	Provide Temporal Gradient values to replace TBDs		
6	Page 2-5 & 2-6, Table 2-3	Provide Spatial Gradient values to replace TBDs		
7	Page 2-6, Section 2.7	Review information and update		
8	Page 3-8, Section 3.2	Provide document number to replace TBDs		
9	Page 3-9, Table 3-1	Provide information to replace TBDs/TBRs		
10	Page 3-10, Table 3-2	Provide values to replace TBDs		
11	Page 3-11, Section 3.2.6	Review and update information		
12	Page 3-11, Section 3.2.8	Review value and update information		
13	Page 3-11 & 3-12, Table 3-3	Provide values to replace TBDs		
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15	Page 3-13, Table 3-5	Provide values to replace TBDs, verify TBR information and update		
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## **1.0 SCOPE**

### **1.1 GENERAL**

This General Subsystem Thermal Specification defines and controls the top level thermal requirements for all components on the Lunar Reconnaissance Orbiter (LRO) spacecraft (SC). The specification places requirements on both sides of the SC-to-component interface to insure mission thermal safety. More details are controlled at lower level specifications such as the Thermal Interface Control Documents (ICD) specified in Section 4.1. This document outlines:

- a. Temperature Requirements
- b. Bounding Environmental Parameters
- c. Thermal Test Requirements
- d. Thermal Analysis Requirements (bounding inputs and required outputs)
- e. Thermal Report Requirements
- f. Component Thermal Hardware Drawings and Diagrams Requirements

### **1.2 PURPOSE**

The purpose of this specification is to clearly define what is expected of every temperature sensitive component to be flown on LRO and the LRO thermal control system to satisfy that the component is safe to fly on LRO. This document is focused on the thermal interface to the SC but also requires that analysis be performed to show thermal safety throughout the powered component during all mission modes.

### **1.3 RESPONSIBILITY**

The Goddard Space Flight Center (GSFC) has the final responsibility for the LRO mission, the Orbiter, its subsystems, and any requirements specifically assigned to LRO in this document.

LRO systems engineering and project management have the ultimate authority to specify thermal requirements. This document shall be the vehicle by which changing thermal requirements are tracked.

### **1.4 DOCUMENTS**

#### **1.4.1 Applicable Documents**

The following documents form a part of this Specification to the extent specified herein:

431-RQMT-000092	Lunar Reconnaissance Orbiter Thermal Math Model Requirements
431-SPEC- <b>TBD</b>	LRO Project <Specific> Thermal Hardware Specification
431-SPEC- <b>TBD</b>	LRO General Thermal Hardware Specification
431-OPS-000042	LRO Mission Concept of Operations

431-SPEC-000008 LRO Electrical Systems Specification

431-SPEC-000112 LRO Technical Resource Allocations Specification

#### **1.4.2 Reference Documents**

GSFC-STD-7000 General Environmental Verification Standards (GEVS) for Flight Programs and Projects

431-ICD-000114 LROC Thermal Interface Control Document

431-ICD-000115 LAMP Thermal Interface Control Document

431-ICD-000116 Diviner Thermal Interface Control Document

431-ICD-000117 LOLA Thermal Interface Control Document

431-ICD-000118 CRaTER Thermal Interface Control Document

431-ICD-000119 LEND Thermal Interface Control Document

431-PLAN- **TBD** LRO Project Thermal Balance/Thermal Vacuum Test Plan

NASA GSFC S311-P-079 Procurement Specification for Thermofoil Heaters

MIL-R-39009 General Specification for Resistors, Fixed, Wire-Wound (Power Type, Chassis Mounted)

NASA GSFC S311-641 Switch, Thermostatic, Bimetallic, SPST, Narrow Differential, Hermetic



## **2.0 TEMPERATURE REQUIREMENTS**

These requirements apply to all flight powered components. To clarify the language used, a brief discussion of temperature limits vocabulary will explain the different types of limits.

### **2.1 TYPES OF TEMPERATURE LIMITS**

There are three sets of temperature limits associated with critical locations and the SC-to-instrument thermal interface locations, defined as follows:

- a. Survival Limits: The minimum and maximum non-operating temperatures that may be experienced without inflicting damage or permanent performance degradation. Components must demonstrate that they can operate properly in thermal vacuum after exposure to cold survival limits. Survival limits must be at least as wide as qualification temperature limits.
- b. Qualification Temperature Limits: The minimum and maximum over which the responsible hardware manager has proven the component works thru qualification. The responsible hardware manager shall induce the qualification temperature limits in thermal vacuum testing prior to delivery to verify that the hardware can operate and survive over the entire specified temperature range.
- c. Flight Design Limits: The flight design limits must be at least 10°C inside the qualification limits, except for actively controlled components. The flight design limits are treated as an “allocation” in the sense that the responsible hardware manager commits to not exceed them by design.

### **2.2 LOCATION OF FLIGHT TELEMETRY**

There shall be temperature limits on all flight telemetry points during all phases of monitoring. However, it is the responsibility of the Orbiter thermal subsystem to only manage telemetry and limits at thermal interfaces that are specified in ICDs or subordinate specifications. These locations are designated by drawings or sketches provided by the responsible hardware manager. This location may be where the component attaches to a SC module deck or on the outside of a mutually agreed up location of the component that shall be clearly defined. Within the component itself, there is likely to be other telemetry which may or may not be monitored by the SC, which shall be the responsibility of the responsible hardware manager. It is the responsibility of the hardware manager to analytically or via test determine that all other temperature limits within the component are met as long as the system thermal interface is maintained within limits (qualification or acceptance). Locations of the temperature limits as defined by the use of telemetry shall be defined by diagram or figure provide in the end item data package (EIDP) prior to delivery of the component to the orbiter assembly in an as-built location. All orbiter-controlled telemetry shall be defined in the Lunar Reconnaissance Orbiter Thermal Hardware Specification (431-SPEC-**TBD**) document or component specific documentation.

### **2.3 FLIGHT INTERFACE DESIGN TEMPERATURE LIMITS**

Table 2-1 below lists the design temperature limits at the SC thermal interface.

**Table 2-1. Spacecraft Temperature Range**

2-1

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SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
<b>Mechanical</b>	Structure Propulsion Module	+70 to -50	+80 to -60
	Structure -Avionics Module	+50 to -50	+60 to -60
	Structure -Avionics to Propulsion	+50 to -50	+60 to -60
	Structure Instrument Module	+50 to -50	+60 to -60
	Fasteners	+90 to -65	+90 to -65
<b>Mechanisms</b>	High Gain Antenna (HGA) Gimbals	-10 to +50	-20 to +60
	HGA Boom	-10 to +50	-20 to +60
	HGA Release and Deploy	-10 to +50	-20 to +60
	Solar Array (S/A) Gimbals	-10 to +50	-20 to +60
	S/A Boom	-10 to +50	-20 to +60
	S/A Release and Deploy	-10 to +50	-20 to +60
<b>Power</b>	Power Subsystem Electronics (PSE)	-10 to 40	-20 to 50
	Battery	10 to 30	0 to 40
	S/A Cells/Cover Glass	+130 (operating), +140 (non-operating) to -170	+140 to -175
	S/A Substrate	+130 (operating), +140 (non-operating) to -170	+140 to -175
<b>Attitude Control System (ACS)</b>	Star Trackers	-30 to +50	-30 to +60
	Inertial Measurement Unit	-30 to +65	-30 to +75
	Reaction Wheels	-10 to +50	-30 to +60
	Coarse Sun Sensors	-120 to +80	-130 to +90
<b>Propulsion and Deployables Electronics (PDE)</b>	Box and MTG Hardware	-10 to +40	-20 to +50
<b>Propulsion (Dry Mass)</b>	Hydrazine Tank 1	+10 to 40	N/A
	Pressure Tanks (Comment)	+0 to 50	N/A
	90N Thrusters	N/A	N/A
	22N Thrusters	N/A	N/A
	High Press Transducers	+10 to 40	N/A
	Low Press Transducer	+10 to 40	N/A
	Gas Latch Valve	+10 to 40	N/A
	Liquid Latch Valve	+10 to 40	N/A
	Fill and Drain	+10 to 40	N/A
	Gas System Filters	+0 to 50	N/A
Liquid Filters	+10 to 40	N/A	

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
	Pressure Regulators	+0 to 50	N/A
	Plumbing Lines	+10 to 40	N/A
	NC Pyro Valves, Pressurant	+0 to 50	N/A
<b>C&amp;DH</b>	Box and Mounting Hardware	-10 to 40	-20 to 50
<b>S Comm</b>	Box and Mounting Hardware	-10 to +40	-20 to 50
	TT&C Omni Antenna	-120 to +80	-130 to +90
<b>Ka Comm</b>	Ka Baseband Modulator	-10 to +50	-20 to 60
	Ka TWTA w/EPC	-10 to +50	-20 to 60
	HGA	+145 to -140	+145 to -140
<b>Cosmic Ray Telescope of the Effects of Radiation (CRaTER)</b>	S/C on I/F to CRaTER	-30 to +35	-40 to +50
<b>Diviner</b>	S/C on I/F to Diviner Instr	-50 to +50	-60 to +60
	S/C on I/F to remote electronics box	-20 to +50	-70 to +80
<b>Lyman-Alpha Mapping Project (LAMP)</b>	S/C at base of LAMP's feet	-50 to +50	-60 to +60
<b>Lunar Exploration Neutron Detector (LEND)</b>	S/C on I/F to LEND	-30 to +40	-40 to +50
<b>Lunar Orbiter Laser Altimeter (LOLA)</b>	S/C on I/F to Optics Package	-50 to +50	-60 to +60
	S/C on I/F to Instrument Electronics	-50 to +50	-60 to +60
<b>Lunar Reconnaissance Orbiter Camera (LROC)</b>	S/C at base of NACS	-50 to +50	-60 to +60
	S/C at base of WACS	-50 to +50	-60 to +60
	S/C at base of SCS	-50 to +50	-60 to +60
<b>Mini RF</b>	S/C at base of antennae's feet	-50 to +50	-60 to +60
	S/C at base of electronics feet	-50 to +50	-60 to +60

## 2.4 TEMPORAL GRADIENT REQUIREMENTS

Table 2-2 below lists the temporal gradient requirements.

**Table 2-2. Temporal Gradient Requirements**

SUBSYSTEM	COMPONENT	TEMPORAL GRADIENT (°C/min)
<b>CRaTER</b>	S/C I/F to the Instrument	None

<b>SUBSYSTEM</b>	<b>COMPONENT</b>	<b>TEMPORAL GRADIENT (°C/min)</b>
<b>Diviner</b>	S/C I/F to Remote Electronics Box	0.3
	S/C I/F to Diviner Instrument	None
<b>LAMP</b>	S/C I/F to LAMP Instrument	None
<b>LEND</b>	Instrument Pkg.#4	2.
<b>LOLA</b>	Optics Package	None
	Instrument Electronics	None
<b>LROC</b>	NAC (2)	None
	WAC	None
	Instrument Electronics	None
<b>Mini-RF</b>	Antennae	None
	Electronics Box	None

## 2.5 SPATIAL GRADIENT REQUIREMENTS

Table 2-3 below lists the spatial gradient requirements.

**Table 2-3. Spatial Gradient Requirements**

<b>SUBSYSTEM</b>	<b>COMPONENT</b>	<b>SPATIAL GRADIENT (°C)</b>
<b>CRaTER</b>	S/C I/F to the Instrument	None
<b>Diviner</b>	S/C I/F to Remote Electronics Box	None
	S/C I/F to Diviner Instrument	5
<b>LAMP</b>	S/C I/F to LAMP Instrument	None
<b>LEND</b>	Instrument Pkg.#4	None
<b>LOLA</b>	Optics Package	None
	Instrument Electronics	None
<b>LROC</b>	NAC (2)	None
	WAC	None
	Instrument Electronics	None
<b>ACS</b>	Star Cameras	None
<b>COMM</b>	Hi-Gain Gimbals	None
<b>Mini-RF</b>	Antennae	None
	Electronics Box	None

## 2.6 TURN ON TEMPERATURE AND SURVIVAL

When powered “OFF”, each component shall be capable of surviving indefinitely when its temperatures are within the qualification survival limits without damage or permanent performance degradation.

All components shall also survive indefinitely, without damage or permanent performance degradation, if powered “ON” anywhere from the minimum survival temperature to 10°C above the maximum operating temperature.

For components that are conductively coupled to the SC, when powered “OFF”, the SC Thermal Control System shall maintain the instruments within the design survival temperature limits. If necessary, the SC will use survival heating as described in Section 3.2.6 to maintain the low limit.

## 2.7 ALLOCATION OF SPACECRAFT MONITORED TEMPERATURE SENSORS

Table 2-4 specifies the number of SC monitored temperature sensors allocated to each component. The current baseline for temperature sensors is 2.252Ω S311P18-02-A-7R6 or PRT (118MF2000AC, 2000 ohms @ 0°C) as specified by the LRO Thermal Subsystem Lead. The thermistor/PRT shall be capable of being read over the all temperature ranges specified. The sensors shall be accurate within 0.5°C from -45 to +75°C.

**Table 2-4. Thermistor Allocation**

Subsystem	Components	Number of Telemetry pts	Internal Box Telemetry
<b>Mechanical</b>		45	
	Comp. Propulsion Module	19	
	Comp. Spacecraft Bus Module	6	
	Comp. Instrument Module	20	
	Fasteners		
<b>Mechanisms</b>		14	
	HGA Gimbals		2 TBR
	HGA Boom		
	HGA Release & Deploy	6	
	S/A Gimbals		2 TBR
	S/A Boom		
	S/A Release & Deploy	6	
	S/A HGA Control Electronics	2	
<b>Thermal</b>		47	
	Thermal Control Heaters	10 (active control)	
	Fuel Tank Heaters	9	
	Fuel Line Heaters	10	
	20# Valve heaters	1	

	5# Valve Heaters	8	
	S/A Gimbal thermal Control		2 TBR
	High Gain Gimbal thermal Control		2 TBR
	Survival Heater Power (Instr I/F)	9	
	Survival Heater Power (S/C elec)		
<b>Power</b>		<b>5</b>	
	PSE	1	5
	Battery	2	2
	S/A Cells/Cover Glass		
	S/A Substrate	2 (PRTs)	4
<b>ACS</b>		<b>9</b>	
	PDE	2	
	Star Trackers	2	3
	Inertial Measurement Unit	1	7
	Reaction Wheels	4	8
	Coarse Sun Sensors		
<b>Propulsion</b>			
	Hydrazine Tank		
	Pressure Tanks		
	20# Thrusters		
	20# Cat Bed		
	5# Thrusters		
	5# Cat Bed		
	Pressure Transducers		
	HP Latch Valves		
	LP Latch Valves (1/4)		
	Fill and Drain		
	Gas System Filters		
	Propellant Filters		
	Pressure Regulators		
	Plumbing Lines		
	NC Pyro Valves		
<b>C&amp;DH</b>		<b>2</b>	
	SBC Card		
	COMM Card		
	Single SSR		
	LISIC		
	HIDEC Card		
	LVPC Card		
	Backplane	2	
	Box amd MTG HDWR		
<b>S Comm</b>		<b>6</b>	
<b>TT&amp;C</b>	TT&C XPDR Stack (xmit)	2	

	TT&C XPDR Stack (Rec)		
	USB Diplexer		
	USB RF Switch		
	USB Coupler		
	USB Hybrid		
	USB Terminator		
	TT&C Omni Antenna	4	
	USB Isolator		
	TT&C Coax Cables		
<b>Relay</b>	Relay Transciever		
	ISM Diplexer		
	ISM RF Switch		
	ISM Hybrid		
	ISM Coupler		
	ISM Terminator		
	Relay Omni Antenna		
	Relay MGA Antenna		
	Relay Coax Cables		
<b>Ka Comm</b>		<b>9</b>	
	Ka Baseband Modulator	2	
	Ka RF Exciter	2	
	Ka SSPA TWTA w/EPC	2	
	Ka Bandreject Filter		
	WG-34 Ka Band Waveguide		
	High Gain Antenna	3	
<b>Electrical</b>			
	Harness		
	Total Instruments	<b>25</b>	
<b>CRaTER</b>	<b>INST #1</b>	<b>2</b>	
	SC I/F to CRaTER	1	
	CRaTER Instr	1	
<b>Diviner</b>		<b>5</b>	
	Diviner Instrument	2	
	Remote Elec Box	1	
	S/C I/F to Diviner + Elec	2	
<b>LAMP</b>	<b>INST #3</b>	<b>2</b>	
	S/C I/F to LAMP	1	
	Instrument	1	
<b>LEND</b>	<b>INST #4</b>	<b>2</b>	
	S/C I/F to LEND	1	
	LEND	1	
<b>LOLA</b>	<b>INST #5</b>	<b>4</b>	

	S/C I/F to LOLA Bench, Elec	2	
	LOLA Optical Bench	1	
	LOLA Electronics	1	
<b>LROC</b>	<b>INST #6</b>	<b>8</b>	
	S/C I/F to LROC	3	
	2 NAC, WAC, SCS, Plate	5	
<b>Mini-RF</b>	<b>Tech Development</b>	<b>2</b>	
	S/C I/F to Antennae	1	
	S/C I/F to Electronics	1	
	S/C SUBTOTAL	137.00	
	INSTRUMENTS TSUBTOTAL	25.00	
	TOTAL	162.00	



### **3.0 THERMAL POWER**

#### **3.1 GENERAL HEATER CIRCUIT REQUIREMENTS**

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

Each component will provide space for mounting thermostats, heaters and temperature sensors. Heaters, if Kapton film heaters, shall comply with NASA GSFC S311-P-079. Heaters, if Vishay Dale Ohm, shall comply with Military/Established Reliability, MIL-R-39009 Qualified, Type RER, R Level, Aluminum Housed, and be Standard (ERH). Mechanical Thermostats, if used, shall comply with NASA GSFC S311-641.

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 Watts per centimeters squared ( $W/cm^2$ ) (1.0 Watts per inch squared [ $W/in^2$ ]) shall be approved by the GSFC LRO Thermal Engineer Lead and may require (if a Kapton heater) bonding with Stycast 2850FT and aluminum over-taping up to  $1.24 W/cm^2$  ( $8.0 W/in^2$ ).

#### **3.2 THERMAL DISSIPATED POWER PER MISSION MODE**

Thermal dissipative power is different from electrical power allocation due to the need to identify the location where the electrical power is dissipated. The purpose for this section is to handshake with the responsible hardware manager what inputs are used in the overall thermal model during which mission mode. Embedded into thermal dissipative power is the need to analyze the worst case orbit average power both high and low even if it is just for one orbit. Table 3-1 shows power dissipations by component without margin. It also details all mission mode that the components shall experience including pointing and SC configuration.

#### **3.3 SPACECRAFT CONTROLLED THERMAL CONTROL HEATER POWER**

The SC shall control several heater power circuits. These heater power circuit sizes and locations are detailed in the Lunar Reconnaissance Orbiter Thermal Hardware Specification (431-SPEC-**TBD**) document. This specification provides details with respect to orbit average heater dissipation and peak power dissipation.

##### **3.3.1 Instrument Operation Heater Power Description**

This switch is intended to service operational heaters in the instrument module. Nominally, the heaters will be located at the component. The sizing of the heaters will be designed such that all components are maintained thermostatically at the low end of the operational temperature range regardless of the actual power that the component is dissipating. In the cold case, this heater power may be close to the orbit average power dissipation of the instrument plus any additional power that is necessary to offset the losses from the instrument to the environment. In the hotter Beta angles, this heater power will be reduced. This heater service will not directly service the

Gyro and Star Trackers on the instrument deck due to their need of operation separate from most instruments. When the instruments are not operating, this heater switch will be switched off to preserve power such as during the lunar eclipse.

### **3.3.2 Spacecraft Operational Thermal Control Heat Power Description**

This switch is intended to service SC components regardless of where they are located (propulsion module, Avionics deck, or instrument module). This switch feeds the separately wired thermostatically controlled operational heaters. These heaters will also provide some heater power to components during cold operational periods that prevent components from exceeding their cold operational temperature due to losses from those components to the cold environment. These SC components will be ones that may be switched off during lunar eclipse or safe hold modes of operation. This heater circuit may be switched off during lower power modes such as lunar eclipse or safe hold and therefore should only service components that either needs tighter stability during certain fully operational modes or components that are

Table 3-1. Component Thermal Power Dissipations

Item	Min Op Powers (W)	Max Op Powers (W)	Min Op Diss (W)	Max Op Diss (W)	Section Numbers	3.0 Thermal Configuration	3.0 Ground In-flight testing	3.2 Pre-Lift off	Launch Safe Hold	4.1 Lift off and Ascent	4.2 Separation	4.3 De-Spin	4.3 SA Deployment	4.4 Lunar Acquisition/ Safe Hold	4.4 Lunar w/RATER, Lend, Gimbal	4.5 Lunar orbit insertion	5.1 SC & Instrument Surv	5.2 Inst & Commissioning	6.2 Measurement Ops	6.3 Station Keeping	6.4 Momentum dumps	6.5 Instrument Calibration	6.6 Lunar Eclipse	6.7 Year Maneuvers	6.8 Safe Hold	7.0 Extended Mission	8.0 End-of-Mission Disposal
Updated 12/6/05	Safe Hold	Safe Hold	Safe Hold	Safe Hold	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	
SC Pointing																											
SC Pointing																											
S/A Deployed?																											
Thermal Cooling Method																											
Time Duration of mode																											
Levenshtein Requirement																											
Deployment Hits On/Off																											
SC Op: Hits On/Off																											
SC Op: Hits On/Off																											
Thermal Dissipation (W)	37.8	37.80	37.8	37.8																							
C&DH (w/CCOM card)																											
S-Band Comm Peak (in C&DH)	15.3	15.3	15.3	15.3																							
S-Band Comm Peak (in C&DH)	0.0	0.0	0.0	0.0																							
S-Band Transponder (6/21/05)	31.0	10.0	10.0	10.0																							
Ka - EPCC/6/21	0.0	0.0	0.0	0.0																							
Ka - TWTA/6/21	0.0	0.0	0.0	0.0																							
Ka - Modulator/6/21	0.0	0.0	0.0	0.0																							
StarTracker (2)	20.0	0.0	0.0	0.0																							
IMU/GYRO	32.0	32.0	32.0	32.0																							
Battery (from 1" Shazers 6/09 with																											
RSSE (from 6/09/05)	67.0	0.0	0.0	0.0																							
RSSE (from 6/09/05)	20.0	0.0	0.0	0.0																							
H-Gain and Solar Array Controller	0.0	0.0	0.0	0.0																							
PDE (includes Gimbal drivers)	0.0	0.0	0.0	0.0																							
S/A Gimbal	10.0	0.0	0.0	0.0																							
H-Gain Gimbal	10.0	0.0	0.0	0.0																							
Min:HF	0.0	0.0	0.0	0.0																							
Dwyer Instrument	0.0	0.0	0.0	0.0																							
Dwyer Remote E-box	0.0	0.0	0.0	0.0																							
LAMP	0.0	0.0	0.0	0.0																							
LOLA MEB	0.0	0.0	0.0	0.0																							
LOLA Main Optical Bench	0.0	0.0	0.0	0.0																							
LROCC decontam	21.0	0.0	0.0	0.0																							
LROCC	0.0	0.0	0.0	0.0																							
Total Inst. Mod	73.0	32.0	32.0	130.2																							
Total Avionics Mod	305.1	123.1	123.1	367.8																							
Total Prop	44.0	37.0	37.0	44.0																							
Total OMS	20.0	0.0	0.0	20.0																							
Total nonheaters	446.1	192.1	192.1	562.0																							
Outputs																											
SC Op: HR Bus																											
Instrument OP: HR Bus																											
Instrument SW: HR Bus																											
Instrument SW: Avionics Header Bus																											
Instrument SW: Avionics Header Bus																											
Total Heaters	0.0	0.0	0.0	0.0																							
Total Thermal Dissipative power	446.1	192.1	192.1	562.0																							

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



switched off automatically during lunar eclipse or safe hold conditions. Examples of these components are the Star Trackers operational, Hi-Gain gimbal operational, and TWTA operational heaters.

### **3.3.3 Tight Bandwidth Command and Data Handling and Software Controlled Heater**

An additional five tight temperature control circuits have not been allocated a location as of this draft. The intention of these heater circuits is to resolve thermal control/stability issues that arise later in the program.

**Table 3-2. Five Tight Control Heaters Powered by C&DH**

<b>Heater # / Max Amp</b>	<b>COMPONENT</b>	<b>Orbit Avg Power at 24 V/Peak Power at 35 V</b>
<b>1/5 amp</b>	<b>Instrument Deck</b>	<b>TBD</b>
<b>2/2 amp</b>	<b>Instrument Deck</b>	<b>TBD</b>
<b>3/2 amp</b>	<b>Instrument Deck</b>	<b>TBD</b>
<b>4/2 amp</b>	<b>Instrument Deck</b>	<b>TBD</b>
<b>5/2 amp</b>	<b>Instrument Deck</b>	<b>TBD</b>

### **3.3.4 Propulsion System Heaters Primary and Redundant Description**

This switch is intended to service the propulsion system heaters and is redundant. The heaters will be located on the thruster valve heaters, propulsion lines, propulsion tanks, and the propulsion pressurization tank. These heaters shall be enabled during all mission modes as they are designed to prevent the Hydrazine from freezing.

### **3.3.5 Deployment Heaters Description**

This switch controls operational thermostatically controlled heaters at the deployment mechanisms and hinges to ensure deployment within the operational range. These heaters will be switched off after deployment to preserve heater power.

### **3.3.6 Essential Heaters Prime and Redundant Description**

These unswitched services are designed to prevent components that are always enabled (essential) during all mission modes from exceeding the lower operational temperature limit and to prevent SC components that may be switched off from exceeding their lower survival temperature limit. The two thermostatically controlled heater circuits shall be offset in setpoint so that their operation can be verified separately during observatory thermal vacuum testing and to prevent the higher peak which would result if the two redundant thermostats sets were to possible snap closed at the same time. Examples of heaters on this circuit would be: C&DH

operational heaters, battery operational heaters, S/A gimbal operational heaters, S-Band operational heater, and Ka band transmitter survival heaters. Heaters for the Gyro (TBR) will be on this circuit.

**3.3.7 Instrument Survival Heaters Description**

This service will primarily service the instruments and instrument module to maintain all the instruments within their cold survival temperature. These heaters shall be wired out from the common service to two separate heater services located on the instruments. It is expected that these services will be thermostatically controlled and may be located on the instruments themselves.

**3.4 SPACECRAFT HEATER ALLOCATION**

The heater allocation listed in Table 3-3 below is very preliminary and will be updated.

**Table 3-3. Spacecraft Control Heater Power Allocations**

<b>SWITCH#</b>	<b>Circuit Description</b>	<b>Volt (Min/Max)</b>	<b>Nominal Predict Power Beta 90° (W)</b>	<b>GEVS Margin</b>	<b>Power Rqmt (W)</b>	<b>Power Rqmt at Beta TBD (W)</b>	<b>Peak Pwr @ Vmax (W)</b>
S11	Instrument Deck Operational	24/35	90 (op case)	1.4	126	<b>TBD</b>	<b>TBD</b>
S38	SC Operational	24/35	48 (op case)	1.4	67	<b>TBD</b>	<b>TBD</b>
S28,S29	Prop System Heaters	24/35	96 (op case) 100 (surv case)	1.4	134 140	<b>TBD</b>	<b>TBD</b>
S39	Deployment Heaters	24/35	30 (TBR)	1.4	42	<b>TBD</b>	<b>TBD</b>
US5,US7	SC Survival	24/35	314 (survival case)	1.4	440	<b>TBD</b>	<b>TBD</b>
US6	Instrument Survival (35.3 W directly on instruments)	24/35	103 (survival case)	1.4	144	<b>TBD</b>	<b>TBD</b>

**3.5 INSTRUMENT HEATER ALLOCATION (WIRED TO SPACECRAFT SWITCH)**

The instrument heater power allocation on the SC Instrument Operational bus is outlined in Table 3-4 and described in Section 3.2.1. The power shown is at 24V and is the size of the heater with the General Environmental Verification Standards (GEVS) margin 70% duty cycle (i.e the powers below are an orbit average with a 70% duty cycle not what the power would be if the heaters were at 100% duty cycle because by design they will not exceed 70%). All services shall be thermostatically controlled at the instrument. The SC is providing no active control. Heaters shall be NASA GSFC S311-079 Kapton film heaters or Vishay Dale Ohm heaters (MIL-R-39009 Qualified) approved by LRO Thermal Subsystem Lead. Mechanical thermostats shall be NASA GSFC S311-641 qualified and have an approved circuit design by the LRO Thermal Subsystem Lead.

**Table 3-4. Instrument Control Heater Power Allocations  
on the SC Instrument Operational Bus**

INSTRUMENT	HEATER POWER (W)		
	Operational	DeContam.	Survival
CRaTER	Sized by S/C	None	<i>Sized by S/C</i>
Diviner (on S/C isolated components only)	7*	None	13*
Diviner Electronics	Sized by S/C	None	<i>Sized by S/C</i>
LROC NAC1	4	8.9**	6
LROC NAC2	4	8.9**	6
LROC WAC	4	2.8**	5
LROC SCS	4	None	5
LAMP	5.5	Dissipated thru LAMP main power feed	8.8
LEND	Sized by S/C	None	<i>Sized by S/C</i>
<i>LOLA Combined</i>	32	<i>None</i>	37.5

\*On Diviner only separate operational and survival heater circuits

\*\*On LROC separate de-contamination heater only circuit

### 3.6 INSTRUMENT HEATER ALLOCATION (CONTROLLED BY COMPONENTS/INSTRUMENTS)

The instrument heater power allocation drawn from the internal instrument power bus is outlined in Table 3-5 as described in the individual instrument ICDs. The power shown is at 24V and is the size of the heater with GEVS margin 70% duty cycle. The power from these heaters will come directly out of the main instrument feeds and will only be operational when the instruments are turned on. Heaters shall be NASA GSFC S311-079 Kapton film heaters or Vishay Dale Ohm heaters (MIL-R-39009 Qualified) approved by LRO Thermal Subsystem Lead. Mechanical thermostats shall be NASA GSFC S311-641 qualified and have an approved circuit design by the LRO Thermal Subsystem Lead.

Table 3-5. Instrument Control Heater Power Allocations

#### Drawn from the Internal Instrument Power Bus

INSTRUMENT	HEATER POWER (W)	
	Operational	DeContam.
CRaTER	None	None
Diviner	None	None
LROC NAC1	None	None
LROC NAC2	None	None

INSTRUMENT	HEATER POWER (W)	
	Operational	DeContam.
LROC WAC	None	None
LROC SCS	None	None
LAMP	None	1.4 W
LEND	4 max	None
LOLA Elec	None	None
LOLA Op Bench/Laser	None	None
LOLA TEC	3 max	None
<i>Total</i>	<i>7</i>	<i>1.4</i>



## **4.0 MULTI-LAYER INSULATION BLANKETS**

### **4.1 OUTER BLANKET COATING**

All exterior facing Multi-Layer Insulation (MLI) blankets in the avionics and instrument module area shall have a 3 mil Kapton with **VDA** in outer coating unless approved by the LRO Thermal Systems Engineer Lead. There will be blankets in the propulsion module area that will need metallic shield outer layers.

### **4.2 MULTI-LAYER INSULATION BLANKET GROUNDING**

All blankets shall be grounded in accordance with the Lunar Reconnaissance Orbiter Electrical Systems Interface Control Document (431-ICD-000018).

### **4.3 MULTI-LAYER INSULATION BLANKET DOCUMENTATION**

All component MLI blankets shall have their location and shape documented in component as-built ICDs. All thermal subsystem MLI blankets shall be documented in the Lunar Reconnaissance Orbiter Project General Thermal Hardware Specification (431-SPEC-**TBD**).

### **4.4 ATTACHMENT OF MULTI-LAYER INSULATION BLANKETS**

All exterior MLI blankets shall be mechanically constrained at least at one point or mechanically captured by another blanket or mechanical component.

**5.0 THERMAL ANALYSIS****5.1 ENVIRONMENTAL CONDITIONS****5.1.1 Thermal Conditions**

The LRO environment is listed in Tables 5-1 and 5-2 below. MLI blankets shall be analyzed using an effective  $\epsilon^*$  equal to 0.005 or 0.03 case specific that yields the worst case in the bounding thermal cases.

**Table 5-1. LRO Solar Constant and Albedo Factor**

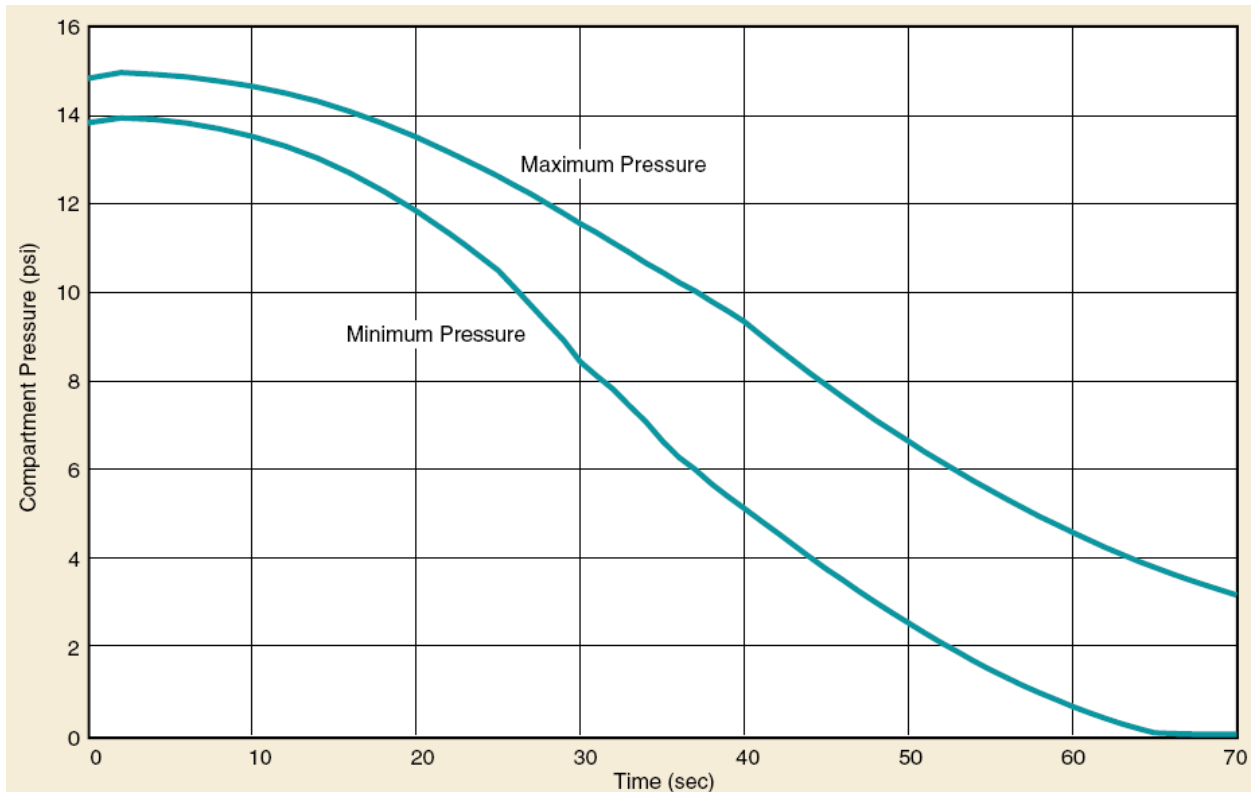
PARAMETER	Cold	Hot
Solar Constant	1280 W/m <sup>2</sup>	1420 W/m <sup>2</sup>
Albedo Factor	0.06	0.13

**Table 5-2. LRO Lunar IR**

ORBIT POSITION (°)	Beta $\theta^\circ$ (W/m <sup>2</sup> )	
	Hot	Cold
0 (sub-solar)	$1335*1*\text{COS}(\theta) + 5$	$1114*1*\text{COS}(\theta) + 5$
30	$1335*0.866*\text{COS}(\theta) + 5$	$1114*0.866*\text{COS}(\theta) + 5$
60	$1335*0.5*\text{COS}(\theta) + 5$	$1114*0.5*\text{COS}(\theta) + 5$
90	5	5
120	5	5
150	5	5
180	5	5
210	5	5
240	5	5
270	5	5
300	$1335*0.5*\text{COS}(\theta) + 5$	$1114*0.5*\text{COS}(\theta) + 5$
330	$1335*0.866*\text{COS}(\theta) + 5$	$1114*0.866*\text{COS}(\theta) + 5$
360 (sub-solar)	$1335*1*\text{COS}(\theta) + 5$	$1114*1*\text{COS}(\theta) + 5$

**5.1.2 Payload Fairing Ascent Pressure Profile**

All MLI blankets and thermal hardware shall be built so that the rapid launch depressurization does not detach any thermal blankets or hardware (see Figure 5-1).



**Figure 5-1. Delta II-Like Fairing Pressure**

**5.2 THERMAL COATINGS**

Recommend adding lead in sentence providing purpose/description of Table.

**Table 5-3. LRO Thermal Coatings**

DESCRIPTION	COLD		HOT 14 mo. (5 yr.)		SPEC.	
	$\alpha_s$	$\epsilon_H$	$\alpha_s$	$\epsilon_H$	SOL	IR
<b>Coatings</b>						
Black Anodize	0.80	0.88	0.92	0.83		
Clear Anodize	TBD	TBD	TBD	TBD		
Irridite	0.10	0.19	0.25	0.11		
Z307 Conductive Black	0.95	0.89	0.97	0.85		
MSA94B Conductive Black	0.94	0.91	0.96	0.87		
Z306 Conductive Black	0.94	0.89	0.95	0.85		
Z93P White Paint	0.17	0.92	0.25 (0.36)	0.87		

DESCRIPTION	COLD		HOT 14 mo. (5 yr.)		SPEC.	
	$\alpha_S$	$\epsilon_H$	$\alpha_S$	$\epsilon_H$	SOL	IR
NS43C Conductive White	0.20	0.91	0.26 (0.37)	0.87		
Vapor Deposited Aluminum	0.08	0.05	0.10	0.03	0.98	0.98
Vapor Deposited Beryllium	TBD	TBD	TBD	TBD		
<b>Films &amp; Tapes</b>						
Kapton, 3-mil	0.45	0.80	0.51 (0.60)	0.76		
OSR Pilkington, 5-mil	0.07	0.80	0.12 (0.19)	0.78	1.0	---
OSR/ITO Pilkington, 5-mil	0.08	0.80	0.15 (0.23)	0.78	1.0	
Silver Teflon Tape, 5-mil	0.08	0.78	0.26 (0.33)	0.73	1.0	---
Silver Teflon Tape, 10-mil	0.09	0.87	0.28 (0.35)	0.83	1.0	---
Silver Teflon, 5-mil	0.08	0.78	0.11 (0.14)	0.73		
Silver Teflon, 10-mil	0.09	0.87	0.13 (0.27)	0.83		
Black Kapton, 3-mil	0.91	0.81	0.93	0.78		
Germanium Black Kapton	0.49	0.81	0.51	0.78		
<b>Miscellaneous</b>						
Solar Cell Triple Junction	0.86	0.87	0.90	0.77	1.0	---
M55J Composite, Bare	0.90	0.79	0.93	0.75		
K1100 Composite, Bare	0.88	0.71	0.91	0.67		
Fused Silica	TBD	TBD	TBD	TBD		
Sapphire Lens	TBD	TBD	TBD	TBD		
Internal Fuel Line	1.0	0.15	1.0	0.15		

### 5.3 HOT AND COLD BIAS OF POWER

Prior to the active measurement of operational power in a flight-like environment, all thermal design shall be able to handle a variation in each mode power  $\pm 10\%$  on constant power components.

### 5.4 MISSION MODES

All components shall meet the appropriate survival or operational limits (component and mission mode specific) per **Table 3-1** during all mission modes.

## **5.5 THERMAL MODEL MARGIN**

Prior to flight, 5°C is the minimum required margin for model predictions with respect to Flight Design Limits, except for heater controlled elements that demonstrate a maximum 70% heater duty cycle.

## **5.6 THERMAL MODELING SCOPE**

The thermal modeling scope for LRO will be different than for other planetary mission's conventional wisdom. Transient analysis will be required to assess hot and cold cases. SC pointing tolerances may drive safe hold cases. Steady sun angles at high Beta angles may drive spatial gradient requirements. The responsible hardware manager shall examine all relevant environments assuming worst case pointing uncertainties in order to determine bounding thermal cases using **Table 3-1** and direction as requested from the LRO Thermal Subsystem Lead.

## **5.7 THERMAL ANALYSIS DOCUMENTATION**

All thermal analysis reports shall clearly outline all assumptions or source of assumptions. They shall detail the modeling technique used, details on the model, graphics and tables showing the temperature results versus requirements and discussion of what the results are sensitive to. It shall be clear what limitations the current analysis is subjected to and what future analyses are planned.

## **6.0 COMPONENT AND ORBITER INTEGRATION AND TEST**

The components and orbiter shall be tested in the bounding thermal cases in thermal vacuum. The target temperatures shall be specified as a result of a test model analysis.

### **6.1 COMPONENT THERMAL CYCLING REQUIREMENT**

All components must be thermally cycled in a thermal vacuum chamber rather than in an air filled chamber. All components shall be flight like blanketed and cycled 8 times (**TBR**) with the thermal interface held at the qualification temperatures listed above at the thermal interface. Durations shall be as recommended in GEVS: components 4 hours, instruments 12 hours. If the component is sensitive to orbit transience, component performance shall be monitored during hot to cold transitions at a rate that a flight like orbit average case might experience. Thermal Vacuum requirement can only be waived through approval of the LRO Thermal Subsystem Lead.

### **6.2 MODEL DOCUMENTATION**

The Reduced Geometric Math Models (RGMMs) and Reduced Thermal Math Models (RTMMs) delivered to GSFC shall be accompanied by appropriate model documentation as specified in the Lunar Reconnaissance Orbiter Thermal Math Model Requirements (431-RQMT-000092) document.

### **6.3 COMPONENT THERMAL TEST MODEL**

All thermal tests shall be Thermal Synthesizer System (TSS)/System Improved Numerical Differencing Analyzer (SINDA) modeled prior to starting the test to derive target temperatures. Target temperatures shall achieve heat flows and effective sink temperatures that closely resemble the flight environment. An analysis report shall be issued which outlines the derivation of the target temperatures. This analysis report should outline all cases that will be assessed in thermal vacuum (i.e. hot case steady state, hot transient, cold steady state, survival, etc.)

### **6.4 COMPONENT THERMAL TEST DOCUMENTATION**

All final thermal qualification test plan shall be approved by the LRO Thermal Subsystem Engineer Lead. Target temperatures and overall test setup shall be discussed with the LRO Thermal Subsystem Engineer Lead.

### **6.5 THERMAL MODEL CORRELATION**

All models shall be correlated within 2°C of every telemetry point with the thermal test model. The thermal test model shall then be reintegrated into the flight model.

## 6.6 REDUCED MODEL

Reduced component models shall be made available to the thermal team 30 days before the Preliminary Design Review (PDR), Critical Design Review (CDR), Pre-Environmental Review (PER), and delivery to Orbiter Integration and Test (I&T). Models requested earlier than this requirement shall be used to pass back to components as bounding system reduced models for component reviews and therefore their delivery dates shall be based on 45 days before the first component review. These models shall utilize the latest known power levels and mechanical configuration. The models shall be correlated with any qualification testing. The reduced model shall be delivered in accordance with the Lunar Reconnaissance Orbiter Thermal Math Model Requirements (431-RQMT-000092).

## 6.7 IN-AIR THERMAL CONTROL

All instruments shall be capable of operating within an ambient air temperature of  $20\pm 5^{\circ}\text{C}$  without degrading instrument performance. No active cooling shall be provided during instrument operation with or without blanket covering. Allowance in the instrument blanket design may be utilized to open higher heat flux areas of the instrument to the surrounding ambient air, but the blanket design shall accommodate opening and closing without blanket damage.

## 6.8 ORBITER THERMAL VACUUM/BALANCE LEVELNESS AND ORIENTATION REQUIREMENTS

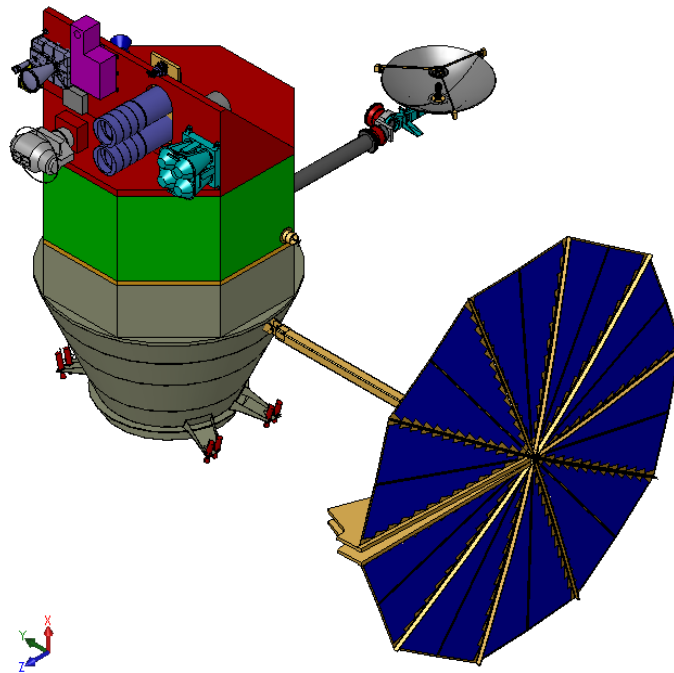
All instruments shall be capable of operating within a thermal vacuum chamber with flight like thermal environment based on the instrument reduced models provided. The horizontal plane will be the X and Y axes with instrument viewing nadir down. There is no known sensitivity to the gravity vector for proper operation during this test of any non-thermal component. Heat Pipes, if they are utilized, will require no more than a  $\pm 0.1^{\circ}/2$  meter tilt in any one location from the horizontal plane.

## 6.9 LUNAR RECONNAISSANCE ORBITER COORDINATE SYSTEM

The LRO mechanical and thermal coordinate system is shown in Figure 6-1. Unless otherwise noted, this document shall refer to the LRO coordinate system.

## 6.10 TEST HEATERS

During Orbiter **TVAC** testing, the configuration of the Orbiter in the vicinity of each component may not be flight like due to placement heater panels and cold plates. The effective sink temperature for some components may be colder than during the mission. Each responsible hardware manager shall anticipate, to the extent possible, such possibilities and provide test heaters in coordination with the **LRO Thermal Lead**. Prior to component I&T the responsible hardware manager in coordination with the **LRO Thermal Lead** shall make a determination of whether test heaters will be required.



**Figure 6-1. LRO Coordinate System Definition**

In such cases, the responsible hardware manager shall supply their own test heaters, cabling and means of control (**TBR**). Any such heaters shall be mounted on the component, not the SC. The component team shall install and control any such test heaters, as needed, to maintain the temperatures of the instrument within the survival range during TVAC.

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

### **6.11 TEST SENSORS**

Test sensors required to verify proper operation of the component during orbiter thermal vacuum testing shall be installed prior to deliver of the component. These sensors shall be identified on as-built drawings using orbiter approved test sensors. A plan shall be also submitted to remove some or all of these sensors before flight. The test sensors that may be read at orbiter thermal vacuum testing will be limited or reduced by the **LRO Thermal Lead** to meet the test setup requirements.



**Appendix A. Abbreviations and Acronyms**

<b>Abbreviation/ Acronym</b>	<b>DEFINITION</b>
ACS	Attitude Control System
°C	Degrees Centigrade
C&DH	Command and Data Handling
CBE	Current Best Estimate
CCB	Configuration Control Board
CCR	Configuration Change Request
CDR	Critical Design Review
CM	Configuration Management
CMO	Configuration Management Office
CRaTER	Cosmic Ray Telescope of the Effects of Radiation
Diviner	Diviner Instrument
ELV	Expendable Launch Vehicle
EPC	???
EVD	???
GEVS	General Environmental Verification Standards
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
HIDEC	???
Htrs	Heaters
I&T	Integration and Test
I/F	Interface
ICD	Interface Control Document
IR	Infrared
IMU	Inertial Measurement Unit
Km	Kilometer
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LISIC	???
LOLA	Lunar Orbiter Laser Altimeter
LROC	Lunar Reconnaissance Orbiter Camera
LRO	Lunar Reconnaissance Orbiter
LVPC	Low Voltage Power Converter
Max.	Maximum
MGA	???
Min.	Minimum
MLI	Multi-Layer Insulation
Mo.	months

<b>Abbreviation/ Acronym</b>	<b>DEFINITION</b>
N/A	Not Applicable
NAC	Narrow Angle Camera
NASA	National Aeronautics and Space Administration
<b>NC</b>	<b>???</b>
<b>OP</b>	Operational
PDE	Propulsion and Deployables Electronics
PDR	Preliminary Design Review
PER	Pre-Environmental Review
<b>PRT</b>	Platinum Resistance Thermistor
PSE	Power Subsystem Electronics
Psi	Pounds per square inch???
<b>Pts</b>	<b>???</b>
Pwr	Power
RF	Radio Frequency
RGMM	Reduced Geometric Math Model
RTMM	Reduced Thermal Math Model
RWA	Reaction Wheel Assembly
S/A	Solar Array
<b>SBC</b>	<b>???</b>
SC	Spacecraft
SCS	Sequencing and Compressor System
Sec.	Seconds
SINDA	Systems Improved Numerical Differencing Analyzer
<b>SOL</b>	<b>Solar</b>
<b>Spec.</b>	Spectularity
SSR	Solid State Recorder
<b>SSPA</b>	<b>???</b>
STS	Space Transportation System
TBD	To Be Determined
TBR	To Be Reviewed
TSS	Thermal Synthesizer System
<b>TT&amp;C</b>	<b>???</b>
<b>TWTA</b>	<b>???</b>
<b>USB</b>	<b>???</b>
W	Watt
w/o	Without
W/cm <sup>2</sup>	Watts per centimeter squared
W/in <sup>2</sup>	Watts per inch squared
W/m <sup>2</sup>	Watts per meter squared

<b>Abbreviation/ Acronym</b>	<b>DEFINITION</b>
WAC	Wide Angle Camera
XPDR	???
V	Volt(s)