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Lunar Reconnaissance Orbiter

Thermal System Specification

August 18, 2005

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Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

CM FOREWORD

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LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

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

Item No.	Location	Summary	Ind./Org.	Due Date
1	Section 1.4.1, 2.2, and 3.3	Provide document numbers to replace TBDs for Specific Thermal Hardware Specs and General Thermal Hardware Specs	C. Baker/ GSCF	8/1/2006
2	Section 1.4.2	Provide document number to replace TBD for LRO Thermal Balance/Thermal Vacuum Test Plan	C. Baker/ GSCF	8/1/2006
3	Table 2-1	Update Structure Temperatures	C. Baker/ GSFC	3/15/2006
4	Section 2.7	Number of Internal Telemetry Points on various components are TBR	Rick Kinder/ OSC	2/1/2006
5	Section 3.3.2, Table 3-1	Need to provide TBRs and TBDs to descriptions of Mission modes when details of Mission Design Concept are completed	Rick Saylor/ HTSI	2/1/2006
6	Section 3.3.3, Table 3-2	Provide Orbit Average Power of Active controlled heater circuits to replace TBDs	C. Baker/ GSCF	8/1/2006
7	Section 3.3.6	Operational versus survival heaters on GYRO located on Essential Heater Bus is TBR.	C. Baker/ GSCF	8/1/2006
8	Section 3.4	Spacecraft Allocations per heater circuit peak and Driving Beta Angles are TBDs	C. Baker/ GSCF	8/1/2006
9	Section 5.2	Thermal Coatings Table has TBDs	W. Peters/ GSFC	12/1/2006

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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-OPS-000042	Lunar Reconnaissance Orbiter Mission Concept of Operations
431-RQMT-000092	Lunar Reconnaissance Orbiter Thermal Math Model Requirements
431-SPEC-000008	Lunar Reconnaissance Orbiter Electrical Systems Specification
431-SPEC-000112	Lunar Reconnaissance Orbiter Technical Resource Allocations Specification

431-SPEC-**TBD**	Lunar Reconnaissance Orbiter General Thermal Hardware Specification
431-SPEC-**TBD**	Lunar Reconnaissance Orbiter Project <Specific> Thermal Hardware Specification

1.4.2 Reference Documents

431-ICD-000114	Lunar Reconnaissance Orbiter Camera Thermal Interface Control Document
431-ICD-000115	Lyman-Alpha Mapping Project Thermal Interface Control Document
431-ICD-000116	Diviner Lunar Radiometer Experiment Thermal Interface Control Document
431-ICD-000117	Lunar Orbiter Laser Altimeter Thermal Interface Control Document
431-ICD-000118	Cosmic Ray Telescope for Effects of Radiation Thermal Interface Control Document
431-ICD-000119	Lunar Exploration Neutron Detector Thermal Interface Control Document
431-PLAN-**TBD**	Lunar Reconnaissance Orbiter Project Thermal Balance/Thermal Vacuum Test Plan
431-SPEC-000012	Lunar Reconnaissance Orbiter Mechanical Systems Specification
GSFC-STD-7000	General Environmental Verification Standards (GEVS) for Flight Programs and Projects
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
NASA GSFC S311-P-079	Procurement Specification for Thermofoil Heaters

2.0 TEMPERTURE 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 Qualification limits are 10 C outside of the Flight Limits. Acceptance Limits are 5 C outside of the Flight Limits. Any component that may be considered for Acceptance testing must present the case to the LRO Thermal Systems Lead that the same design component has been qualified in a relevant environment for LRO. 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 Operational Limits: The flight operational limits must be at least 10°C inside the qualification limits, except for actively controlled components. The flight operational 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 applicable component mechanical interface drawings 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. Inside box/ component locations are acceptable if installed by component development team. 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

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
Mechanical	Structure Propulsion Module	-50 to +70 (**TBR**)	-60 to +80
	Structure -Avionics Module	-50 to +50 (**TBR**)	-60 to +60
	Structure –Avionics to Propulsion	-50 to +50 (**TBR**)	-60 to +60
	Structure - Instrument Module	-50 to +50 (**TBR**)	-60 to +60
Mechanisms	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 (SA) Gimbals	-10 to +50	-20 to +60
	SA Boom	-10 to +50	-20 to +60
	SA Release and Deploy	-10 to +50	-20 to +60
Power	Power Subsystem Electronics (PSE)	-10 to +40	-20 to +50
	Battery	+10 TBR to +30	+0 to +40
	SA Cells/Cover Glass	-170 to +130 (operating), +140 (non-operating)	-175 to +140
Attitude Control System (ACS)	Star Trackers	-30 to +50	-35 to +60
	Inertial Measurement Unit	-30 to +65	-35 to +75
	Reaction Wheels	-10 to +50	-30 to +60
	Coarse Sun Sensors	-130 to +110	-140 to +120

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
Propulsion and Deployables Electronics (PDE)	Box and MTG Hardware	-10 to +40	-20 to +50
Propulsion System (wetted components only)	Liquid side components	+10 to +50	N/A
	Gas side components upstream or regulator	-40 to +40	N/A
	90N Thrusters	N/A	N/A
	22N Thrusters	N/A	N/A
	High Press Transducers	+10 to +50	N/A
	Low Press Transducers	+10 to +50	N/A
	All gas line components downstream of regulator	+10 to +50	N/A
	NC Pyro Valves, Pressurant	+0 to +50	N/A
C&DH	Box and Mounting Hardware	-10 to +40	-20 to +50
S Comm	S-Band Transponder	-10 to +40	-20 to +50
	TT&C Omni Antenna	-120 to +80	-130 to +90
Ka Comm	Ka Baseband Modulator	-10 to +50	-20 to +60
	Ka TWTA w/EPC	-10 to +50	-20 to +60
	HGA	-140 to +145	-140 to +145
Cosmic Ray Telescope of the Effects of Radiation (CRaTER)	SC on I/F to CRaTER	-30 to +35	-40 to +50
Diviner	SC on I/F to Diviner Instr	-50 to +50	-60 to +60
	SC on I/F to remote electronics box	-20 to +50	-70 to +80
Lyman-Alpha Mapping Project (LAMP)	SC I/F at base of LAMP's feet	-50 to +50	-60 to +60
Lunar Exploration Neutron Detector (LEND)	SC on I/F to LEND	-30 to +40	-40 to +50
Lunar Orbiter Laser Altimeter (LOLA)	SC on I/F to Optics Package	-50 to +50	-60 to +60
	SC on I/F to Instrument Electronics	-10 to +40	-20 to +50
Lunar	SC at base of NAC	-50 to +50	-60 to +60

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
Reconnaissance Orbiter Camera (LROC)	SC I/F at base of WAC	-50 to +50	-60 to +60
	SC I/F at base of SCS	-50 to +50	-60 to +60
Mini RF	SC I/F at base of antennae's feet	-50 to +50	-60 to +60
	SC I/F 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)
CRaTER	SC I/F to the Instrument	None
Diviner	SC I/F to Remote Electronics Box	0.3
	SC I/F to Diviner Instrument	None
LAMP	SC I/F to LAMP Instrument	None
LEND	Instrument Pkg.#4	2.
LOLA	Optics Package	None
	Instrument Electronics	None
LROC	NAC (2)	None
	WAC	None
	Instrument Electronics	None
Mini-RF	Antennae	None
	Electronics Box	None

2.5 SPATIAL GRADIENT REQUIREMENTS

Table 2-3 below lists the spatial gradient requirements between mounting feet.

Table 2-3. Spatial Gradient Requirements

SUBSYSTEM	COMPONENT	SPATIAL GRADIENT Between Mounting Feet (°C)
CRaTER	SC I/F to the Instrument	None
Diviner	SC I/F to Remote Electronics Box	None
	SC I/F to Diviner Instrument	5.
LAMP	SC I/F to LAMP Instrument	None
LEND	Instrument Pkg.#4	None
LOLA	Optics Package	None
	Instrument Electronics	None
LROC	NAC (2)	None
	WAC	None
	Instrument Electronics	None
ACS	Star Cameras	None
COMM	Hi-Gain Gimbals	None
Mini-RF	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 telemetry types listed only apply to the column in the table labeled "Number of Telemetry Points'. The 'Internal Box Telemetry' sensors can be alternative telemetry types since they may be read by alternative avionics. The current baseline for temperature sensors is 2.252 ohms S311P18-02-A-7R6 or Platinum Resistance Thermistor (PRT) (118MF2000AC, 2000 ohms @ 0°C) as specified by the LRO Thermal Systems 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. The thermistor electrical interface shall be per the relevant electrical ICD and that the physical placement of each thermistor is per the relevant thermal ICD.

Table 2-4. Thermistor Allocation

Subsystem	Components	Number of Telemetry pts	Reference Internal Box Telemetry
Mechanical		45	
	Comp. Propulsion Module	19	
	Comp. Spacecraft Bus Module	6	
	Comp. Instrument Module	20	
	Fasteners		
Mechanisms		14	
	HGA Gimbals		2 TBR
	HGA Boom		
	HGA Release & Deploy	6	
	SA Gimbals		2 TBR
	SA Boom		
	SA Release & Deploy	6	
	SA HGA Control Electronics	2	
Thermal		48	
	Thermal Control Heaters	10 (active control)	
	Fuel Tank Heaters	9	
	Fuel Line Heaters	10	
	20# Valve heaters	2	
	5# Valve Heaters	8	
	SA Gimbal thermal Control		2 TBR
	High Gain Gimbal thermal Control		2 TBR
	Survival Heater Power (Instr I/F)	9	
	Survival Heater Power (SC elec)		
Power		3	
	PSE	1	0
	Battery	2	1
	SA Cells/Cover Glass		

Subsystem	Components	Number of Telemetry pts	Reference Internal Box Telemetry
ACS		9	
	PDE (1)	1	8
	Star Trackers (2)	2	2
	Inertial Measurement Unit (1)	1	4
	Reaction Wheel (4)	4	8
	Coarse Sun Sensor (8)	0	0
Propulsion			
	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		
C&DH		2	
	SBC Card		
	S-COMM Card		
	Ka-COMM Card		
	Disk Interface Board (DIB)		
	Thermal Card		
	HK/IO Card		
	LVPC Card		
	Backplane		
	Multi-Function Analog Card (MAC)		
	Box and Mounting HDWR	2	
S Comm		6	
TT&C	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	

Subsystem	Components	Number of Telemetry pts	Reference Internal Box Telemetry
	USB Isolator		
	TT&C Coax Cables		
Ka Comm		9	
	Ka Baseband Modulator	2	
	Ka TWTA	2	
	Ka EPC	2	
	Ka Bandreject Filter		
	WG-34 Ka Band Waveguide		
	High Gain Antenna	3	
Electrical			
	Harness		
	Total Instruments	25	
CRaTER	**INST #1**	2	
	SC I/F to CRaTER	1	
	CRaTER Instr	1	
Diviner		5	
	Diviner Instrument	2	
	Remote Elec Box	1	
	SC I/F to Diviner + Elec	2	
LAMP	**INST #3**	2	
	SC I/F to LAMP	1	
	Instrument	1	
LEND	**INST #4**	2	
	S/C I/F to LEND	1	
	LEND	1	
LOLA	**INST #5**	4	
	SC I/F to LOLA Bench, Elec	2	
	LOLA Optical Bench	1	
	LOLA Electronics	1	
LROC	**INST #6**	8	
	SC I/F to LROC	3	
	2 NAC, WAC, SCS, Plate	5	
Mini-RF	**Tech Development**	2	
	SC I/F to Antennae	1	
	SC I/F to Electronics	1	
	S/C SUBTOTAL	135.00	
	INSTRUMENTS TSUBTOTAL	25.00	
	TOTAL	160.00	

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±7V.

Each component shall 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 modes 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 Operational 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

Table 3-1. Component Thermal Power Dissipations

Updated 09/12/05	Sun Acq Powers max (W)	Safe Hold Powers min (W)	Lunar Eclipse Powers (W)	Max Op Diss Pwr (Eclipse no margin)	Min Op Diss Pwr (No Eclipse no margin)	Section Numbers are from 431-OPS-000042	3.0 Thermal Vacuum Configuration	3.0 Ground in-air testing	3.2 Pre-Lift off	4.1 Lift off and Ascent	4.2 Separation	4.3 De-Spin	4.3 S/A Deployment	4.3 Sun Acquisition/ Safe Hold	4.4 Lunar Cruise	4.5 Lunar orbit Insertion	5.1 S/C Activation & Commissioning	5.2 Instr Activation & Commissioning	6.2 Measurement Ops	6.2.3 Off Nadir Pointing	6.3 Station Keeping	6.4 Momentum dumps	6.5 Instrument Calibration	6.6 Lunar Eclipse	6.7 Yaw Maneuvers	6.8 Safe Hold	7.0 Extended Mission	8.0 End-of-Mission Disposal
							All	All	Launch Safe Hold	Launch Safe Hold	Launch Safe Hold	Safe Hold	Safe Hold	Safe Hold w/PDE	w/CRaTER, Lend, Gimbals	Safe Hold w/CRaTER, Lend, Gimbals	SC Op, Instrument Surv	Op	Op	Op	Op	Op	Op	Safe hold Cold	Op	Safe Hold Cold	Safe Hold Hot	Safe Hold Hot
S/C Pointing							X and Y axis horizontal	Y and Z axis horizontal, X and Y axis horizontal	+X VV	+X VV to 60 RPM roll, +X axis within 15 deg of either the sun or anti-sun at third stage ignition.	~2 deg/sec Rotation +X axis is within 15 deg of either the sun or anti-sun.	~2 deg/sec Rotation +X axis at separation is within 15 deg of either the sun or anti-sun.	May stop rotation, but X or -X is +/- 15 deg on sunline	Reorient +/- 15° -Y on sun line	+/-5° -Y on sun line, Yaw to fire thrusters (sun can be on all X and Y surfaces)	30 x 216 km orbit, nadir pointing, Yaw to fire thrusters, but sun is +/-15 degrees on +X or -X axis	30 x 216 km orbit (see details in 5.2), nadir pointing, could be any Beta, May off point 5° for gyro calibration	30x216 km altitude about the moon. the periselene, 30 km, over the lunar south pole. it will vary by no more than 3 deg over the month. also, orbit shape varies from 26x216 to 45x197 Nadir pointing is nominal	50+/-20 km Nadir Pointing +/-1 arcminute	50 +/-20 km Nadir +/-20 off yaw must return to nadir in less than 15 minutes	50+/-20 km Nadir Pointing +/-1 arcminute will require 180 degree yaw (sun may get on the anti-sun - slews take 10 min each way, 5 min dwell)	50+/-20 km Nadir Pointing +/-10 degrees off nadir possible for up to 5 min	Off Nadir pointing not allowed to drive thermal but TBD	Sun Acq Attitude max roll off -Y to sun for 160 minutes is <10 degrees for all three axises (depending on <2 deg starting tolerance)	50 +/-20 km Nadir (sun kept off anti-sun during 10 minute 180 deg yaw)	-Y pointing +/-15°	Nadir Pointing 30 x 216 km	Nadir pointing, sun may be on anti-sun side
Hi-Gain deployed?							Deattached	Varies	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
S/A deployed?							Deattached	Varies	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Thermal Cooling Method							Targets	Convection & A/C	Convection & Fairing	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation
Time Duration of mode									L-5 min on Battery	L + 1396 s 3rd Stg Burn, L + 1596 s Sep	<10 minutes	<10 minutes	<15 minutes	<15 minutes	5.2 Days	TBD Maximum Thruster fire	1 month	1 month	1 year	<20 minutes	1 Orbit total	1 Orbit total	25 minutes max	160 minute + eclipse	1 Orbit total	Variable	~4 year	<30 minutes
Levelness Requirement							<+0.1" / 2 meters	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
Deployment Htrs On/Off									On	On	On	On	On	On	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
S/C Op Htrs On/Off									Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	Off	On	Off	On	Off
Instr Op Htrs On/Off									Off	Off	Off	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	Off	On	Off	On	Off
Thermal Dissipation (W)																												
C&DH (w/o COMM card)	37.8	37.8	37.80	37.80	37.8				37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
S-Band Comm Peak (in CD&H)	15.3	15.3	15.3	15.3	15.3				15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
S/K-Band Comm Peak (in CD&H)	0.0	0.0	0.0	5.1	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	5.1	5.1	5.1	0.0	0.0	0.0	5.1	0.0	0.0	0.0
DDA Drivers (in CD&H)	7.0	0.0	0.0	7.0	7.0				0.0	0.0	0.0	0.0	0.0	0.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	0.0	7.0	0.0	7.0	7.0
DDA Box	3.2	0.0	0.0	3.2	3.2				0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	0.0	3.2	0.0	3.2	3.2
S-Band Transponder (6/21/05)	31.0	10.0	10.0	23.4	10.0				10.0	10.0	10.0	10.0	10.0	10.0	31.0	31.0	31.0	23.4	23.4	23.4	31.0	31.0	31.0	10.0	23.4	10.0	31.0	31.0
Ka - EPC 6/21	0.0	0.0	0.0	3.6	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	3.6	3.6	3.6	0.0	0.0	0.0	3.6	0.0	0.0	0.0
Ka - TWTA 6/21	0.0	0.0	0.0	22.1	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.1	22.1	22.1	22.1	0.0	0.0	0.0	22.1	0.0	0.0	0.0
Ka - Modulator 6/21	0.0	0.0	0.0	15.4	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	15.4	15.4	15.4	0.0	0.0	0.0	15.4	0.0	0.0	0.0
RWAs (4)	64.0	64.0	64.0	64.0	64.0				20.0	20.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0
Star Trackers (2)	20.0	0.0	0.0	20.0	20.0				0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	0.0	20.0	0.0	20.0	20.0
IMU/GYRO	35.0	35.0	35.0	35.0	35.0				35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Battery (From T. Spitzer's 6/05 with 700 W bus)	67.0	0.0	0.0	67.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	0.0	0.0	0.0	67.0	0.0	67.0	67.0
PSE (From T. Spitzer's07/06/05)	90.0	60.0	60.0	90.0	70.0				60.0	60.0	60.0	60.0	60.0	60.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	70.0	70.0	60.0	90.0	60.0	90.0	90.0
Hi-Gain and Solar Array Controller	20.0	0.0	0.0	20.0	20.0				0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	0.0	20.0	0.0	20.0	20.0
PDE (includes Gimbal drivers)	0.0	0.0	0.0	30.0	0.0				0.0	0.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	0.0	0.0	0.0	30.0	0.0	0.0	0.0
S/A Gimbal	10.0	0.0	0.0	10.0	10.0				0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	10.0	0.0	10.0	10.0
Hi-Gain Gimbal	10.0	0.0	0.0	10.0	10.0				0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	10.0	0.0	10.0	10.0
CRaTER	0.0	0.0	0.0	4.6	4.6				0.0	0.0	0.0	0.0	0.0	0.0	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	0.0	4.6	0.0	0.0	0.0
Mini-RF	0.0	0.0	0.0	6.2	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	6.2	6.2	6.2	0.0	0.0	0.0	6.2	0.0	0.0	0.0
Diviner Instrument	0.0	0.0	0.0	4.2	4.2				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	4.2	4.2	4.2	4.2	4.2	0.0	4.2	0.0	0.0	0.0
Diviner Remote E-box	0.0	0.0	0.0	6.8	6.8				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.8	6.8	6.8	6.8	6.8	6.8	0.0	6.8	0.0	0.0	0.0
LAMP	0.0	0.0	0.0	5.8	4.4				0.0	0.0	0.0	0.0	0.0	0.0	5.8	5.8	5.8	5.8	5.8	5.8	5.8	4.4	4.4	0.0	5.8	0.0	0.0	0.0
LEND	0.0	0.0	0.0	13.0	13.0				0.0	0.0	0.0	0.0	0.0	0.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	0.0	13.0	0.0	0.0	0.0
LOLA MEB	0.0	0.0	0.0	16.0	14.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	16.0	16.0	16.0	16.0	16.0	0.0	16.0	0.0	0.0	0.0
LOLA Main Optical Bench	0.0	0.0	0.0	17.0	7.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0	17.0	17.0	17.0	7.0	7.0	0.0	17.0	0.0	0.0	0.0
LROC decontam	98.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0	98.0	98.0	98.0	98.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LROC	0.0	0.0	0.0	20.8	17.6				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	20.8	20.8	20.8	17.6	17.6	0.0	20.8	0.0	0.0	0.0
Total Instr Mod	153.0	35.0	35.0	133.2	118.0				35.0	35.0	35.0	35.0	35.0	35.0	170.6	170.6	170.6	231.2	133.2	133.2	133.2	120.0	120.0	35.0	133.2	35.0	55.0	55.0
Total Avionics Mod	271.3	123.1	123.1	356.0	171.9				113.1	113.1	143.1	143.1	143.1	143.1	247.1	247.1	247.1	252.2	252.2	252.2	252.2	130.1	130.1	123.1	356.0	171.9	217.1	217.1
Total Prop	64.0	64.0	64.0	64.0	64.0				30.0	30.0	74.0	74.0	74.0	74.0	95.0	95.0	95.0	128.4	128.4	128.4	136.0	95.0	95.0	64.0	64.0	64.0	95.0	95.0
Total Others	20.0	0.0	0.0	20.0	20.0				0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	0.0	20.0	20.0	20.0	20.0
Total non-heaters	508.3	222.1	222.1	573.2	373.9				178.1	178.1	252.1	252.1	252.1	252.1	532.7	532.7	532.7	631.8	533.8	533.8	541.4	365.1	365.1	222.1	573.2	373.9	387.1	387.1
Outputs																												
S/C Op Htr Bus																												
Instrument Op Htr Bus																												
S/C Survival Heater Bus																												
Instrument Survival Heater Bus									0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							0.0			35.6	35.6
Propulsion System heater bus																												
Total Heaters	0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.6	35.6
Total Thermal Dissipative power	508.3	222.1	222.1	573.2	373.9				178.1	178.1	252.1	252.1	252.1	252.1	532.7	532.7	532.7	631.8	533.8	533.8	541.4	365.1	365.1	222.1	573.2	373.9	422.7	422.7

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 switched off automatically during lunar eclipse or safe hold conditions. Examples of these components are the Star Trackers operational, Hi-Gain gimbal operational, and Traveling Wave Tube Amplifier (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 locations. 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

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

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 Heater 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, SA gimbal operational heaters, S-Band operational heater, and Ka band transmitter survival heaters. Heaters for the Gyro (**TBR**) will be on this circuit. Also included are survival heater for avionics that require them in nobn-operational modes.

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

Circuit Description	Volt (Min/Max)	Nominal Predict Power Beta 90° (W)	GEVS Margin	Power Rqmt (W) at 24 V	Power Rqmt (W) at 35 V	Power Rqmt at Beta TBD (W)	Peak Pwr @ Vmax (W)
Instrument Deck Operational	24/35	90 (op case)	1.4	126	268	**TBD**	**TBD**
SC Operational	24/35	48 (op case)	1.4	67	143	**TBD**	**TBD**
Prop System Heaters	24/35	96 (op case) 100 (surv case)	1.4	134 140	285 298	**TBD**	**TBD**

Circuit Description	Volt (Min/Max)	Nominal Predict Power Beta 90° (W)	GEVS Margin	Power Rqmt (W) at 24 V	Power Rqmt (W) at 35 V	Power Rqmt at Beta TBD (W)	Peak Pwr @ Vmax (W)
Deployment Heaters	24/35	30 (TBR)	1.4	42	89	**TBD**	**TBD**
SC Survival	24/35	314 (survival case)	1.4	440	936	**TBD**	**TBD**
Instrument Survival (35.3 W directly on instruments)	24/35	103 (survival case)	1.4	144	306	**TBD**	**TBD**

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 Systems Lead. Mechanical thermostats shall be NASA GSFC S311-641 qualified and have an approved circuit design by the LRO Thermal Systems 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	Sized by S/C
Diviner (on S/C isolated components only)	7*	None	13*
Diviner Electronics	Sized by S/C	None	Sized by S/C
LROC NAC1	4	32.8**	6
LROC NAC2	4	32.8**	6
LROC WAC	4	16.4**	5
LROC SCS	4	None	5

INSTRUMENT	HEATER POWER (W)		
	Operational	**DeContam.**	**Survival**
LAMP	5.5	Dissipated thru LAMP main power feed	8.8
LEND	Sized by S/C	None	Sized by S/C
LOLA Combined	32	None	37.5
Mini-RF	None	None	10

*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 Systems Lead. Mechanical thermostats shall be NASA GSFC S311-641 qualified and have an approved circuit design by the LRO Thermal Systems 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
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

INSTRUMENT	HEATER POWER (W)	
	Operational	**DeContam.**
LOLA TEC	3 max	None
Total	**7**	**1.4**

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 Vapor Deposited Aluminum (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 Specification (431-ICD-000008).

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 Electrical Systems Specification (431-SPEC-000008).

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 ε* 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^2	1420 W/m^2
Albedo Factor	0.06	0.13

Table 5-2. LRO Lunar Infrared

ORBIT POSITION (°)	Beta θ° (W/m^2)	
	Hot	Cold
0 (sub-solar)	(1335-5)*1*COS(θ) + 5	(1114-5)*1*COS(θ) + 5
30	(1335-5)*0.866*COS(θ) + 5	(1114-5)*0.866*COS(θ) + 5
60	(1335-5)*0.5*COS(θ) + 5	(1114-5)*0.5*COS(θ) + 5
90	5	5
120	5	5
150	5	5
180	5	5
210	5	5
240	5	5
270	5	5
300	(1335-5)*0.5*COS(θ) + 5	(1114-5)*0.5*COS(θ) + 5
330	(1335-5)*0.866*COS(θ) + 5	(1114-5)*0.866*COS(θ) + 5
360 (sub-solar)	(1335-5)*1*COS(θ) + 5	(1114-5)*1*COS(θ) + 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).

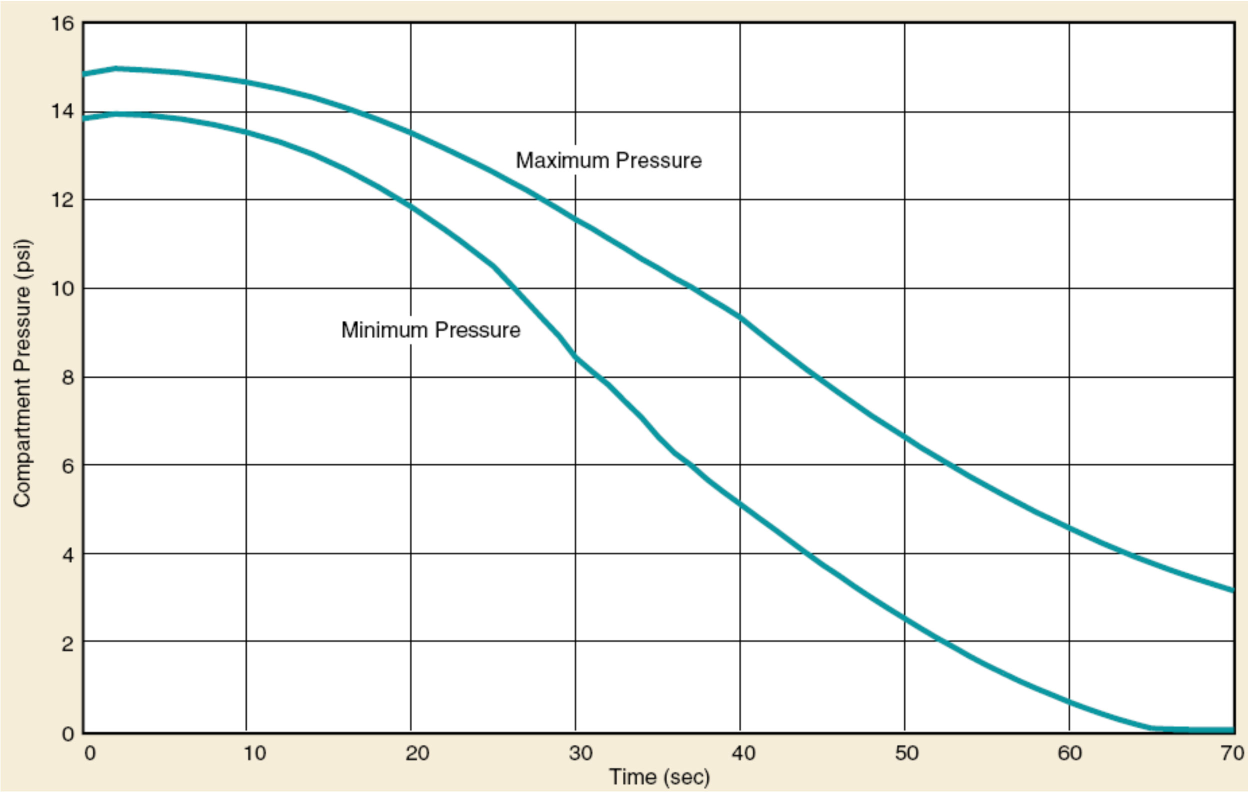

Figure 5-1. Delta II-Like Fairing Pressure

5.2 THERMAL COATINGS

Table 5-3. LRO Thermal Coatings

DESCRIPTION	COLD		HOT 14 mo. (5 yr.)		SPEC.	
	α_S	ε_H	α_S	ε_H	SOL	IR
Coatings						
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.	
	α_S	ε_H	α_S	ε_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**		
Films & Tapes						
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		
Miscellaneous						
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 ±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 Operational 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 Systems 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. All thermal hardware shall comply with the Lunar Reconnaissance Orbiter Mechanical Systems Specification (431-SPEC-000012).

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 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 Systems 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 Anaylzer (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 Systems Lead. Target temperatures and overall test setup shall be discussed with the LRO Thermal Systems 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±5°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 ±0.1”/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 thermal vacuum (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 Systems Lead. Prior to component I&T the responsible hardware manage in coordination the LRO Thermal Systems Lead shall make a determination of whether test heaters will be required.

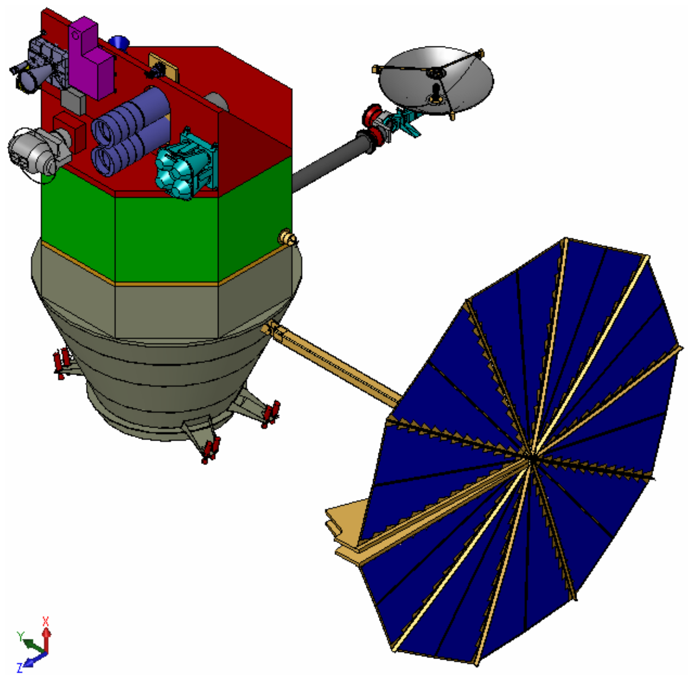

Figure 6-1. LRO Coordinate System Definition

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 Systems Lead to meet the test setup requirements.

Appendix A. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
ACS	Attitude Control System
ºC	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	Electrical Power Conditioner
EVD	Engine Valve Driver
GEVS	General Environmental Verification Standards
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
HKIO	House Keeping Input Output
Htrs	Heaters
I&T	Integration and Test
I/F	Interface
ICD	Interface Control Document
IR	Infared
IMU	Inertial Measurement Unit
Km	Kilometer
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LOLA	Lunar Orbiter Laser Altimeter
LROC	Lunar Reconnaissance Orbiter Camera
LRO	Lunar Reconnaissance Orbiter
LVPC	Low Voltage Power Converter
Max.	Maximum
Min.	Minimum
MLI	Multi-Layer Insulation
Mo.	Months
MTG	Mounting
N/A	Not Applicable
NAC	Narrow Angle Camera
NASA	National Aeronautics and Space Administration

Abbreviation/ Acronym	DEFINITION
NC	Normally Closed
OP	Operational
PDE	Propulsion and Deployable Electronics
PDR	Preliminary Design Review
PER	Pre-Environmental Review
PRT	Platinum Resistance Thermistor
PSE	Power Subsystem Electronics
Psi	Pounds per square inch
Pts	Points
Pwr	Power
RF	Radio Frequency
RGMM	Reduced Geometric Math Model
RTMM	Reduced Thermal Math Model
RWA	Reaction Wheel Assembly
S/A	Solar Array
SBC	Single Board Computer
SC	Spacecraft
SCS	Sequencing and Compressor System
Sec.	Seconds
SINDA	Systems Improved Numerical Differencing Analyzer
SOL	Solar
Spec.	Spectularity
SSR	Solid State Recorder
STS	Space Transportation System
TBD	To Be Determined
TBR	To Be Reviewed
TSS	Thermal Synthesizer System
TT&C	Telemetry Tracking and Control
TWTA	Traveling Wave Tube Amplifier
USB	Universal System Bus
VDA	Vapor Deposited Aluminum
W	Watt
w/o	Without
W/cm^2	Watts per centimeter squared
W/in^2	Watts per inch squared
W/m^2	Watts per meter squared
WAC	Wide Angle Camera
XPDR	Transponder
V	Volt(s)