CRaTER
Thermal-Balance
Test Procedure

Dwg. No. 32-06005.02

Revision A
November 28, 2007

S/N:_________ Date:_________
Table of Contents

PREFACE ................................................................................................................................. 5

1 INTRODUCTION .................................................................................................................... 6

1.1 Activity Description ........................................................................................................... 6

1.2 Test Item Description ....................................................................................................... 6

1.3 Support Item Description .................................................................................................. 6
  1.3.1 Thermal-Vacuum Chamber ............................................................................................ 6
  1.3.2 TQCM .......................................................................................................................... 7
  1.3.3 Radiation Source .......................................................................................................... 7
  1.3.4 Spacecraft Simulator .................................................................................................. 7
  1.3.5 28VDC Power Supply ................................................................................................ 7
  1.3.6 Data Logger for Chamber Environment ...................................................................... 7
  1.3.7 Computer Workstation ............................................................................................... 7

2 REQUIREMENTS ...................................................................................................................... 8

2.1 Verification Plan ................................................................................................................ 8

2.2 Temperature Limits – Thermal Balance ........................................................................... 8

2.3 Temperature Tolerance ..................................................................................................... 8

2.4 Temperature Slew Rates .................................................................................................. 8

2.5 Order of Tests .................................................................................................................. 8

2.6 Required Items ................................................................................................................ 8

2.7 Success Criteria – Thermal Balance ................................................................................ 9

2.8 Documents to be on Hand ............................................................................................... 9

3 CONFIGURATION .................................................................................................................... 10

3.1 General Constraints ........................................................................................................ 10

3.2 Nomenclature .................................................................................................................. 10

3.3 Test Configuration ........................................................................................................... 10

3.4 Hazardous Commands ................................................................................................... 10

3.5 Instrument Purge ............................................................................................................. 10
4  PROCEDURES -- Initialization ................................................................. 11

4.1 Identification of Equipment and Personnel ........................................... 11

4.2 Data Logging ....................................................................................... 11

4.3 Install Instrument in Chamber .............................................................. 12
  4.3.1 Prepare the Vacuum Chamber ......................................................... 12
  4.3.2 Install Instrument on Interface Plate ................................................. 12

4.4 Baseline Chamber Cleanliness ............................................................... 12

4.5 Check out the EGSE ........................................................................... 13

4.6 Pump Down the Chamber .................................................................. 13

4.7 Initial Outgassing Period .................................................................... 13

4.8 Cool Chamber Shroud ....................................................................... 13

4.9 Initial Instrument Verification .............................................................. 13

4.10 General Instrument Monitoring .......................................................... 13

5  PROCEDURES – Temperature Dwell ....................................................... 14

5.1 Cold Survival Thermal Balance ........................................................... 14

5.2 Cold Thermal Balance ....................................................................... 14

5.3 Purge Chamber Shroud ...................................................................... 15

5.4 Hot Thermal Balance ......................................................................... 15

6  PROCEDURES – Wrap-Up ..................................................................... 16

6.1 Power off Instrument ........................................................................ 16

6.2 Thermal Control of the Interface Plate ............................................... 16

6.3 Vent the Thermal-Vacuum Chamber ................................................ 16

6.4 Remove Instrument from Chamber .................................................... 16
  6.4.1 Remove Instrument from Interface Plate ......................................... 16
  6.4.2 Secure the Vacuum Chamber ......................................................... 16

7  In Case of Test Failure ........................................................................ 17

7.1 Chamber Anomalies .......................................................................... 17
7.2 Workstation Anomalies

7.3 Spacecraft Simulator

7.4 General Procedure Errors

7.5 Independence

APPENDIX A – RED/YELLOW LIMITS

APPENDIX B – INTERNAL TEMP MONITOR LOCATIONS

APPENDIX C – EXTERNAL TEMP MONITOR LOCATIONS
Preface

Revision A is for use at the Lincoln Laboratory facility. Much of the text is copied from the Thermal-Vacuum Test Procedure, 32-06005.01.
1 Introduction

The flight hardware for the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument on the Lunar Reconnaissance Orbiter (LRO) is composed of a single assembly incorporating both radiation detector and all associated power, command, data processing, and telemetry electronics.

1.1 Activity Description

This procedure will provide test data for correlation with the instrument thermal model.

A graphical timeline of the activities described here is given by the TB Temperature Profiles (32-06005.0201)

1.2 Test Item Description

Six silicon particle detectors (labeled D1, D3, D5 for the “thin” 140um units; D2, D4, D6 for the “thick” 1000um units) are arranged in a stack with intermediate cylinders of Tissue Equivalent Plastic (TEP). When used in coincidence, these detectors form a crude telescope with a 35 degree field-of-view. Charge collected by each detector is separately amplified, filtered, and converted by an A/D converter. The six values of deposited charge form a hextuple of 12-bit values that comprise the primary science data for a single event. The FPGA packs a series of these hextuples into a CCSDS primary science telemetry packet for transmission to the spacecraft data system. Similarly, secondary science information (e.g.: rejected event rates) and analog housekeeping values are packed by the FPGA into their own CCSDS telemetry packets. All telemetry is transmitted on a MIL-STD-1553 data bus.

Similarly, all instrument commands are received from the spacecraft via the 1553 bus.

Six internal instrument temperatures are read out through the normal flight telemetry stream:

- telescope – this is a good representation of the TEP and detector temperatures
- analog board – the analog board has no point heat sources
- digital board – this is the temperature of the case of the hottest component (the 1553 transceiver)
- DC-DC converter – the case temperature of the hotter of the two converters
- bulkhead – the wall separating the electronics box from the telescope volume
- PRT reference – located on the bulkhead adjacent to the above sensor

Note that the “PRT reference” is normally read out by the spacecraft telemetry system; only in the stand-alone instrument test configuration is it read out in the instrument telemetry stream. The location of these sensors is shown in Appendix B – Internal Temp Monitor Locations.

1.3 Support Item Description

1.3.1 Thermal-Vacuum Chamber

The NUVAC thermal vacuum chamber is located in a cleanroom at Lincoln Laboratory. It contains a gravity fed liquid nitrogen cooled shroud with inside dimensions of about 6' diameter x 12' long. The vacuum system includes a large oil roughing pump with a
liquid nitrogen cold trap, a roots blower, a 20" CVI cryo pump and an 8" CTI cryo pump for backup. The chamber is capable of reaching a pressure of 10-8 torr with the cold wall filled.

1.3.2 TQCM
A Thermoelectric Quartz Crystal Microbalance (TQCM) is provided to assess the cleanliness of the chamber environment.

1.3.3 Radiation Source
No radiation source is used in this procedure.

1.3.4 Spacecraft Simulator
The spacecraft simulator is composed of a single-board-computer (SBC) married to a MIL-STD-1553 bus controller. The SBC is programmed to interrogate the instrument on a fixed cadence, retrieving up to 25 primary science packets per second, 1 secondary science packet per second, and 1 housekeeping packet per second. (Once integrated with the LRO spacecraft, the housekeeping packets are retrieved only once every 16 seconds, but the packets are available from the instrument at the higher rate, since the instrument runs at a one second cadence.)

1.3.5 28VDC Power Supply
A standard laboratory DC power supply, adjustable over the range of 27 to 35 VDC, 0.5 amperes maximum, is required to power the instrument.

1.3.6 Data Logger for Chamber Environment
The Chamber Data Logger acquires low time resolution data about chamber and external instrument temperatures. A desktop computer running Benchlink Datalogger will read the test thermocouples through an Agilent 34970 multiplexer. Test temperatures will be measured and recorded once per minute.

1.3.7 Computer Workstation
To support the monitoring of environment variables from the data logger in addition to the command and data interface to the instrument via the spacecraft simulator, a computer workstation is required. This workstation is also responsible for logging all data into standard LRO-format data files. Our software will run on UNIX, Mac, or Windows operating systems which support UDP network connections to the spacecraft simulator and data logger and have both Perl and TCL/Tk available to run the scripts.
2 Requirements

2.1 Verification Plan
This Procedure supports the Instrument Performance and Environmental Verification Plan (32-01206).

2.2 Temperature Limits – Thermal Balance
The test temperature requirements for Thermal Balance are taken from Table 2-1 of the LRO Thermal System Specification, 431-SPEC-000091, Rev C. These are not based on flight predicts of the internal reference temperatures but on the specified limits on the spacecraft side of the interface – in this case the plate to which the instrument under test is mounted.
- Hot balance: +25 C
- Cold balance: -30 C
- Survival balance: -40 C

2.3 Temperature Tolerance
The tolerance on all test temperatures is ±2C.

2.4 Temperature Slew Rates
Thermal slews will be controlled to occur at a maximum rate of 0.6C/min.

2.5 Order of Tests
The individual tests may be performed in any order which proves convenient.

2.6 Required Items
- Thermal-vacuum chamber
- TQCM
- Kapton tape, acrylic supplied by GSFC.
- Chamber data logger
- Volt meter
- Torque Wrench
- Instrument mounting hardware
- Spacecraft Simulator
- 28VDC Adjustable Power Supply
- Flight CRaTER Instrument w/Thermal Blanket
2.7 Success Criteria – Thermal Balance

There are no success criteria for the tests as performed by this procedure; we are merely collecting data here. Success is defined by the thermal model matching these results within tolerances defined by the model requirements.

2.8 Documents to be on Hand

- 32-06003.02 Instrument Short Form Functional Test Procedure (3 copies)
- Mate/Demate Log
3 Configuration

3.1 General Constraints

Electrostatic Discharge (ESD) protection procedures per MIT 99-01003 shall be observed.

Connector mating/demating procedures per MIT 99-03002 shall be observed. Any connections made directly to the unit under test shall be noted in the mate/demate log.

The flight instrument shall be maintained in a clean environment per MIT 32-01203 or equivalent. In addition the thermal-vacuum chamber must be verified clean (using the TQCM or other comparable methods) prior to installation of the instrument in the chamber.

The laboratory power supply shall be operated only within the range of 27 to 35 VDC.

A three-digit, calibrated digital voltmeter shall be used for the initial setup of the input power. No other calibrated equipment is required.

3.2 Nomenclature

The Electrical Ground Support Equipment (EGSE) consists of a 28 VDC power supply, a Ballard Technologies single board computer with 1553 interface (the spacecraft simulator), the Chamber Data Logger, a computer workstation, and associated cabling.

The interface plate is a ½" thick black anodized aluminum plate that provides a hole pattern equivalent to the spacecraft mechanical interface. It is thermally isolated from the rest of the chamber and temperature controlled by the combination of a heater and radiative coupling to the LN2 chamber shroud. The heater is powered by a dedicated control unit with over and under temperature alarms. The instrument and blanket are, in turn, mounted on the interface plate.

3.3 Test Configuration

The flight instrument with a representative thermal blanket is configured for test inside the thermal-vacuum chamber located at MIT Lincoln Laboratory with connections made through the chamber wall to the laboratory power supply and spacecraft simulator.

3.4 Hazardous Commands

It is not permissible to turn on the detector bias supply in partial vacuum environments where the pressure is between 525 torr (10K feet altitude nominal) and $10^{-3}$ torr.

3.5 Instrument Purge

The instrument should be purged prior to returning the instrument to storage at MIT after testing; see the Instrument GN2 Purge Procedure (32-06003.06). Nominal completion of this procedure will result in that happening as part of the chamber vent cycle.
4 Procedures -- Initialization

Space is provided for the recording of information of particular significance in the conduct of this test. Where a value simply needs to be verified, as opposed to recorded, a simple check mark √ will suffice. In addition the Test Conductor may redline the procedure to more accurately document the actual flow of events, both routine and anomalous. An example of this would be that the Thermal Balance dwells are done on only one flight unit and hence skipped on the alternate unit.

The pages of this section will be attached to the Test Report that is filed for each instrument on which this activity is conducted. That is also true of the as-run copies of the Short and Long Form Test Procedures. The telemetry data stream generated by the spacecraft simulator and chamber data logger is an integral part of the Test Report; that data is archived on crater.bu.edu.

4.1 Identification of Equipment and Personnel

Flight Instrument, 32-10000  S/N ___________
Spacecraft Simulator, 32-80201  S/N ___________

Principal Test Conductor

Other Test Conductors

QA Representative:

Other Individuals:

4.2 Data Logging

The general intent is to log the instrument and chamber data continuously for the duration of this test procedure. Since standard archive process date-stamps the file names, and every CCSDS data packet is time-tagged, we can, after the fact, stitch together a continuous archival record. The important point for the test conductor is not to terminate a data log archive at the conclusion of any short or long form functional test, but simply to let it run. (At maximum event rate we generated< about 1GB/day.)
4.3 **Install Instrument in Chamber**

4.3.1 **Prepare the Vacuum Chamber**

Clean room garment, hat, and clean latex gloves shall be worn during this operation.

1. Install interface plate to TV chamber with two 5/16-18 bolts at far end and support the middle with Teflon spacers. Torque bolts to secure plate but not compress Teflon spacers.
2. Mount bulkhead connector and cable along with pigtai cable for instrumentation.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

4.3.2 **Install Instrument on Interface Plate**

ESD precautions must be met. Clean room attire shall warn: ESD-safe clean gloves, ESD clean room smock, ESD wrist strap, hair net must be worn.

1. Remove vent plug at the Nitrogen purge inlet.
2. Remove vent cover at the purge outlet, if applicable.
3. Place the CRaTER assembly onto Interface Plate being careful not to bump into the Blanket buttons. Ensure cables and RTD wires are clear.
4. Secure to Interface Plate with clean Silver plated 10-32 x .625” min SHCS. Torque to 25 in lbs.
5. Connect vacuum feedthru interface cables (1553, 1 Hz clock, power) to the instrument.
6. Install thermocouples per Appendix C.
7. Install Thermal Blanket onto telescope section. Secure top hat retaining button to the bottom of the telescope housing using a 6-32 x ½” min SHCS. Torque to 8 in-lbs.
8. Install thermal blanket onto E-box cover buttons. Retain with kapton tape. Secure thermal blanket to interface plate with kapton tape.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

4.4 **Baseline Chamber Cleanliness**

At some time prior to this test the chamber must be subjected to a “dry run” before the instrument and its thermal blanket are installed. With the interface plate held at +35C and the TQCM held at −20C, an empty-chamber cleanliness level must be established. All cabling internal to the vacuum system shall also be included in the chamber test.

<table>
<thead>
<tr>
<th>TQCM Drift</th>
<th>Date of Test</th>
<th>Initial</th>
</tr>
</thead>
</table>
4.5 **Check out the EGSE**
Connect the external 1553, 1Hz clock, and 28VDC power cables to the Spacecraft Simulator and run a Short Form Functional to demonstrate basic aliveness. In addition to a normal Short Form, check out the alternate 1553 connection. The instrument should be left in a powered down state.

<table>
<thead>
<tr>
<th>Pass/Fail</th>
<th>Instr. State</th>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Off?</td>
<td></td>
<td></td>
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</tbody>
</table>

Connect the external cables to the Chamber Data Logger and verify that all environmental channels and the TQCM monitor are functioning properly.

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<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

4.6 **Pump Down the Chamber**
Following the standard Lincoln Vacuum Pumpdown Procedure, pump down the chamber. Continue on to the next step when the pressure is less than $5 \times 10^{-5}$ torr.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

4.7 **Initial Outgassing Period**
Command the chamber baseplate to +40C. Continue on to the next step when the pressure is again less than $5 \times 10^{-5}$ torr (or when the Contamination Engineer feels we can proceed).

<table>
<thead>
<tr>
<th>Date</th>
<th>Chamber Pressure</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

4.8 **Cool Chamber Shroud**
Fill the chamber shroud with LN2 per Lincoln Lab procedure.

4.9 **Initial Instrument Verification**
Perform a Short Form Functional. The instrument should be powered off at the end of this procedure.

<table>
<thead>
<tr>
<th>Pass/Fail</th>
<th>Instr. State</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Off?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.10 **General Instrument Monitoring**
As the instrument operates more or less continuously during this test, the test conductor must monitor the data to assure that nothing untoward – or even unusual – is happening between the benchmark test events. In particular both instrument and facility data should be monitored carefully during temperature transitions.
5 Procedures – Temperature Dwell

5.1 Cold Survival Thermal Balance

Command the chamber baseplate to -40°C.

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<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
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</table>

At 30 minute intervals record the external instrument temperature data using the data sheet (with the instrument unpowered, no internal telemetry is available). Balance is achieved when, after a minimum of 5 hours, there is no change in any of the instrument temperatures of more than 0.5 degree C in the previous 3 hours.

<table>
<thead>
<tr>
<th>Time</th>
<th>Initial</th>
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</thead>
<tbody>
<tr>
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</table>

5.2 Cold Thermal Balance

Command the chamber baseplate to -30°C.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

When the interface plate first reaches its target temperature (it is not necessary to wait for the whole instrument to stabilize), run a Short Form Functional, stopping at the conclusion of para 4.7 Check Detector Noise Levels. This will leave the instrument running in its nominal on-orbit condition.

<table>
<thead>
<tr>
<th>Pass/Fail</th>
<th>Instr. State</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On?</td>
<td></td>
<td></td>
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</tbody>
</table>

At 30 minute intervals record the instrument temperature data using the data sheet. Balance is achieved when, after a minimum of 5 hours, there is no change in any of the instrument temperatures of more than 0.5 degree C in the previous 3 hours.

<table>
<thead>
<tr>
<th>Time</th>
<th>Initial</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.3 **Purge Chamber Shroud**

Purge the chamber shroud with ambient temperature air per Lincoln Laboratory procedure.

5.4 **Hot Thermal Balance**

Command the chamber baseplate to +25°C. To measure blanket properties properly, we really want the chamber pressure below $1 \times 10^{-5}$ torr.

<table>
<thead>
<tr>
<th>Date</th>
<th>Chamber Pressure</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

At 30 minute intervals record the instrument temperature data using the data sheet. Balance is achieved when, after a minimum of 5 hours, there is no change in any of the instrument temperatures of more than 0.5 degree C in the previous 3 hours.
6 Procedures – Wrap-up

6.1 Power off Instrument
Power off the instrument following para 4.8 Clean Up and Shut Down of the Short Form Functional.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

6.2 Thermal Control of the Interface Plate
Control interface plate to +30C.

<table>
<thead>
<tr>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

6.3 Vent the Thermal-Vacuum Chamber
Backfill chamber with nitrogen gas.

<table>
<thead>
<tr>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

6.4 Remove Instrument from Chamber

6.4.1 Remove Instrument from Interface Plate
ESD precautions must be met. Clean room attire shall warn: ESD-safe clean gloves, ESD clean room smock, ESD wrist strap, hair net must be worn.
1. Verify that the EGSE has been powered down.
3. Remove thermocouples from instrument.
4. Disconnect vacuum feedthru interface cables from the instrument (J1-J4)
5. Update mate/demate log.
6. Loosen and remove 10-32 hardware that secures CRaTER to the Interface Plate.
7. Lift CRaTER Assembly off of Interface Plate
8. Install vent plug at the instrument Nitrogen purge inlet
9. Install vent cover, if applicable, at the instrument purge outlet

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>

6.4.2 Secure the Vacuum Chamber
We will not provide details here since what one does depends upon the following use of the chamber. Rely on the guidance of the Contamination Engineer.

<table>
<thead>
<tr>
<th>Time</th>
<th>Initial</th>
</tr>
</thead>
</table>
7 In Case of Test Failure

7.1 Chamber Anomalies
In case of electrical power failure you must perform the steps in Section 2.5 of the Vacuum Pumpdown and Venting Procedure document. Note that the TQCM will have to be shut off if the chamber pressure rises above \(1 \times 10^{-5}\) torr. The instrument should also be powered down if the pressure rises above this value. (The instrument bias supply does not like partial vacuum; normal atmospheric conditions are fine.)

7.2 Workstation Anomalies
These procedures assume you have logged in as the canonical test operator, “jennyg” – password available from your local guru. If using the 12” Mac laptop, you need to be operating in the X Windows environment. The discrete telltales in the CRaTER Command Window will not function; just ignore references to those items in the Short Form.

When using a standalone system with a network hub, the CRaTER EGSE (the OmniBusBox) will typically have a port address of 192.168.1.10. You can use the “ping 192.168.1.100”, etc. to find the OmniBusBox or a web browser with the address http://192.168.1.100.

Note that if the power is cycled to the Spacecraft Simulator, any current invocations of CHouse, CCmd, etc. will have to be closed and the programs restarted. (Each application program makes a specific request to the Simulator for a data feed, and these requests do not persist over a power cycle.)

Most other workstation problems will probably require the assistance of a guru.

7.3 Spacecraft Simulator
The spacecraft simulator starts the CRaTER 1553 server (omniserver) and packet distribution program (pdist) automatically upon power-on boot. A healthy Ethernet connection is indicated by the blinking green status light on the front of the OmniBusBox.

The 1553 server defaults to using the A side 1553 bus (only) on power up. The server can be commanded (button on lower left of the workstation command window) to use the B side. All command and telemetry will operate normally in this mode, and all test procedures may be run in this condition without modification.

The spacecraft simulator also generates the 1 Hz tick. This signal may be commanded ON/OFF by a button on the lower left of the workstation command window (it will be ON by default on power up.)

Lacking success, there is little more the casual user can do but recheck the cables and cycle the power.

7.4 General Procedure Errors
A time stamp is generated by the spacecraft simulator once per second, converted into LRO-standard Mission Elapsed Time and sent to the Instrument in a 1553 data packet. That time stamp is then attached to each CCSDS telemetry packet returned by the
Instrument. The GSE displays unpack those MET timestamps and convert them back into standard wall-clock format. The end result: if the GSE time displays are incrementing once per second, the entire end-to-end command-instrument-telemetry system is working. And, if not, there is no sense in proceeding on until that problem is solved.

7.5 Independence

Each dwell or balance in this procedure is really an independent test and, as such, can be executed separately from the rest if a procedural or GSE failure causes an interruption. One must only be careful that the final conditions of the previous test (e.g.: instrument power off) are met when picking up a test sequence in the middle.

A true test failure, on the other hand, will require that – after failure resolution – the test sequence is restarted from the beginning. Even here, however, the thermal balance, thermal cycling, and cleanliness monitoring are still separate entities, combined in this one procedure merely as a matter of convenience.
Appendix A – Red/Yellow Limits

**Instrument Limits**

<table>
<thead>
<tr>
<th>Monitor</th>
<th>Red Low</th>
<th>Yellow Low</th>
<th>Yellow High</th>
<th>Red High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope</td>
<td>-50</td>
<td>-45</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Analog Board</td>
<td>-50</td>
<td>-45</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Digital Board</td>
<td>-50</td>
<td>-45</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td>Power Converter</td>
<td>-50</td>
<td>-45</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Bulkhead</td>
<td>-50</td>
<td>-45</td>
<td>40</td>
<td>50</td>
</tr>
</tbody>
</table>

**Facility Limits**

<table>
<thead>
<tr>
<th>Monitor</th>
<th>Red Low</th>
<th>Yellow Low</th>
<th>Yellow High</th>
<th>Red High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface Plate</td>
<td>-50</td>
<td>-45</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Cold Wall and Carriage</td>
<td>-200</td>
<td>-190</td>
<td>30</td>
<td>40</td>
</tr>
</tbody>
</table>
Appendix B – Internal Temp Monitor Locations

Reference Location

PRT on inner wall between electronics enclosure and telescope assembly
Analog Board

AD590 on analog board
Digital Board

AD590 on 1553 Transceiver
DID we get rid of the PRT on the bulkhead?

- PRT on bulkhead
- AD590 on bulkhead
- AD590 on power converter
Appendix C – External Temp Monitor Locations

Thermocouples and Blankets

[Diagram showing various locations labeled with numbers]

Crater blanket not shown

Thermocouple Locations

[Diagram showing another set of locations labeled with numbers]

MIT Lincoln Laboratory

32-06005.02 Page 25 of 25 Revision A