CAL Document Change Notification

DCN No. 7650-DCN-0084-01

CHANGE TITLE: CAL Verification And Test Plan, Update To Flight Flow And Peformance

☒ **Internal** ☐ **External**

ORIGINATOR: J. Eric Grove **DATE:** 1-Sep-04 **NEXT ASSY:**

DOC or DWG NUMBER	TITLE	AFFECTED REV.	NEW REV.
LAT-MD-01345	CAL Verification And Test Plan	01	02

CHANGE DESCRIPTION:

1. Many clarifications of language, many repairs to improper paragraph numbering, throughout.
2. Updated verification matrix and verification plan to reflect flight Level IV specs.

REASON FOR CHANGE:

These changes were made to reflect lessons learned from EM assembly and test.

DISPOSITION OF HARDWARE:

☐ **No hardware affected**

☒ **Serial numbers affected:** All CAL Modules **Effective date:** 1-Sep-04

	Use as is	Retest	Rework	Scrap	Other/Comment
Raw material	☐	☐	☐	☐	
Parts in process	☐	☐	☐	☐	
Assemblies	☒	☐	☐	☐	

APPROVALS	DATE	OTHER APPROVALS (specify):	DATE
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SUBSYSTEM MANAGER: *W.N. Johnson*		**ELECTRICA ENGINEER:** *J. Ampe*	
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QUAL ASSUR. MANAGER: *N. Virmani*		:	
CONFIGURED AND RELEASED: *P. Sandora*			

GLAST LAT MANAGEMENT DOCUMENT	Document # **LAT-MD-01345-02**	Date Effective 1 Septemper 2004
	Prepared by(s) J. Eric Grove	Supersedes LAT-SS-00222
	Subsystem/Office Calorimeter Subsystem	
Document Title **LAT Calorimeter Verification & Environmental Test Plan**		

Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT) Calorimeter

Verification & Environmental Test Plan

DOCUMENT APPROVAL

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CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes
D1	17 January 2003	Initial Draft
01	13 February 2003	Initial Release
02	2 Sept 2004	Many changes to reflect flight flow, flight Level IV spec

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to establish the basic requirements for each LAT CAL component and module as derived from the LAT Program Instrument Performance Verification Plan. It outlines the testing to be performed at the engineering model, qualification, and acceptance test phases.

1.2 SCOPE

The scope of this document illustrates the various testing phases in which each component and completed CAL Module shall experience in order to be considered flight ready. Performance and Science requirements are verified by a combination of testing and analysis at the qualification test level for the Engineering Model (EM), and the Qualification Model (QM). Final flight production CAL Modules are deemed qualified by similarity from the Qualification process and undergo a less intensive test at the acceptance level.

1.3 APPLICABLE DOCUMENTS

Documents and drawings that are applicable to this procedure are listed below.

1.3.1 Documents

GEVS-SE	General Environmental Verification Specification For STS & ELV Payloads, Subsystems, and Components
GSFC-433-MAR-0004	GLAST Mission Assurance Requirements for the Large Area Telescope Phase C/D/E
GSFC-433-RQMT-0005	Electromagnetic Interference (EMI) Requirements Document
LAT-MD-00039	LAT Performance Assurance Implementation Plan
LAT-MD-00228	GLAST LAT CAL, TKR, & DAQ Contamination Control Plan
LAT-MD-00408	LAT Program Instrument Performance Verification Plan
LAT-SS-00115	LAT Mechanical Systems – Level III Specification
LAT-SS-00210	LAT-CAL Subsystem Level IV Specification
LAT-SS-00222	Calorimeter Module Assembly, Test, and Calibration Requirements
LAT-SS-00231	Calorimeter Performance Acceptance Standards and Tests
LAT-SS-00262	Calorimeter Module Assembly and Test Plan
LAT-SS-00778	GLAST LAT Environmental Specification
LAT-SS-01370	Calorimeter Environmental Test Procedure
LAT-SS-01371	Calorimeter Functional Test Procedure
LAT-SS-01372	Calorimeter Qualification Test Procedure
LAT-SS-01373	Calorimeter Acceptance Test Procedure
LAT-SS-01498	AFEE Board Verification Plan
LAT-SS-02235	CDE Acceptance Test Plan
LAT-SS-02236	CDE Qualification Test Plan
LAT-TD-00464	GLAST LAT Calorimeter FMEA, RBD, Predictions and CIL
MIL-STD-461E	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
NASA-STD-8739.7	Electrostatic Discharge Control

1.3.2 Drawings

LAT-DS-00916	CAL Module
LAT-DS-01224	PEM Assembly Drawing
LAT-DS-04536	CAL Tower Module

1.4 DEFINITIONS AND ACRONYMS

1.4.1 Acronyms

AFEE	Analog Front End Electronics of the Calorimeter
CAL	Calorimeter Subsystem of the LAT
CDE	Crystal Detector Element of the PEM
CPT	Comprehensive Performance Test
CsI	Cesium Iodide
DAS	Data Acquisition System
DPD	Dual Pin Diode
EGSE	Electrical Ground Support Equipment
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FM	Flight Model
GLAST	Gamma-Ray Large Area Space Telescope
GSE	Ground Support Equipment
LAT	Large Area Telescope
LPT	Limited Performance Test
MECO	Main Engine Cut Off
MGSE	Mechanical Ground Support Equipment
PEM	Pre Electronic Module of the CAL
PIN	Positive Intrinsic Negative
RFU	Release For Use
SFM	Structural Flight Model
SM	Structural Model
TBD	To Be Determined
TBR	To Be Resolved
TEM	Tower Electronics Module
TRR	Test Readiness Review
WOA	Work Order Authorization

1.4.2 Definitions

Acceptance Test	The validation process that demonstrates the hardware is acceptable for flight. It also serves as a quality control screen to detect deficiencies and, normally, to provide the basis for delivery of an item under terms of contract
Analysis	A quantitative evaluation of a complete system and/or subsystems by review/analysis of collected data
cm	centimeter
Demonstration	To prove or show, usually without measurements of instrumentation, that the project/product complies with requirements by observation of the results.
Electromagnetic Compatibility (EMC)	The condition that prevails when various electronic devices are performing their functions according to design in a common electromagnetic environment.
Electromagnetic Interference (EMI)	Electromagnetic energy that interrupts, obstructs, or otherwise degrades or limits the effective performance of electrical equipment.
Electromagnetic Susceptibility	Undesired response by a component, subsystem, or system to conducted or radiated electromagnetic emissions.
eV	Electron Volt
Inspection	To examine visually or use simple physical measurement techniques to verify conformance to specified requirements.
kg	kilogram
MeV	Million Electron Volts, 10^6 eV
mm	millimeter
Operate	The ability to withstand the applied environment without malfunction, loss of capability, change of operation state/mode, memory changes or need for outside intervention. Operate is the ability of an instrument to execute all ancillary and housekeeping tasks including self-test, but does not include the ability to take scientific data.
Perform	The ability to execute its science mission or to meet its specified performance. Performance requires that the Operate criteria be met.
Performance Test	The operation of a unit in accordance with a defined operational procedure to determine whether performance is within the specified requirements. Two types of performance tests within this document are the Limited Performance Test (Functional) and the Comprehensive Performance test.
Qualification Test	Tests intended to demonstrate that the test item will function within performance specifications under simulated conditions more severe than those expected from ground handling, launch, and orbital operations. Their purpose is to uncover deficiencies in design and method of manufacture. They are not intended to exceed design safety margins or to introduce unrealistic modes of failure.
sec	seconds
Simulation	To examine through model analysis or modeling techniques to verify conformance to specified requirements
Survive	The ability to withstand the applied environment without any permanent loss of performance capability. Survival is required for both powered and unpowered states.

Testing	A measurement to prove or show, usually with precision measurement or instrumentation, that the project/product complies with requirements.
Validation	Process used to assure the requirement set is complete and consistent, and that each requirement is achievable.
Verification	Process used to ensure that the selected solutions meet specified requirements and properly integrate with interfacing products

2 SYSTEM DESCRIPTION

Figure 1 shows the Calorimeter Module in an exploded view. The module consists of the Pre-Electronics Module (PEM) Mechanical Structure, Crystal Detector Elements (CDE), Closeout Plates, AFEE boards and Side Panels. The complete assembled and integrated CAL Module shall be the article of test within this document. There shall be two (2) distinct versions of the CAL Module assembled and tested prior to commencement of the flight production models. These are the Engineering and Qualification Models. Upon successful completion of the testing of these two units, the Flight CAL Modules, seventeen (17) in total, shall begin the production and test phase.

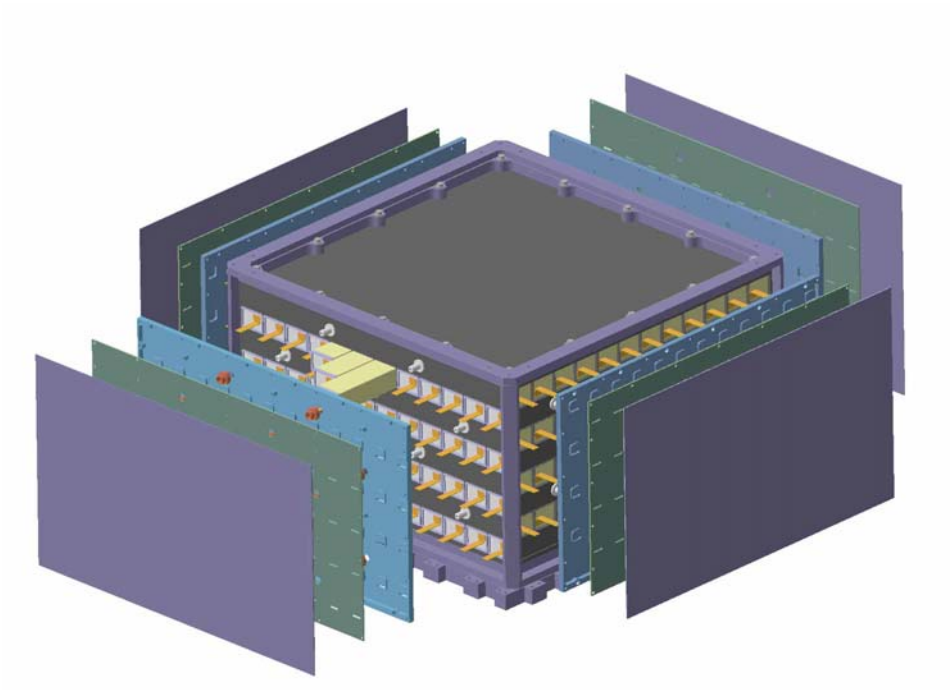

Figure 1: GLAST Calorimeter Module – (Exploded View)

3 VERIFICATION PLAN

3.1 Overview

The LAT CAL Subsystem plans a comprehensive performance verification program in which the performance requirements found in the CAL Subsystem Level IV Specification, [LAT-SS-00210] are verified by a combination of testing and analysis. This verification process is conducted at the component or module level, and then followed through to the integrated subsystem and then later to the LAT system integration levels.

Qualification of the Flight CAL Modules is accomplished through the development and test at qualification levels of two CAL models; the Engineering and Qualification models as well as qualification of a Structural Model and a Structural Flight Model. Those specific tests for the flight units that qualification by similarity to the EM, QM, SM, and SFM modules do not cover shall undergo testing at acceptance levels. This plan covers the verification of the CAL component or module for the Engineering, Structural, Structural Flight, Qualification, and Flight Models.

3.2 Objectives

The objectives of the verification program for the GLAST Calorimeter Modules are as follows:

a) Provide assurance that specified science requirements will be met.

b) Provide assurance that the hardware will meet specific performance, interface, and safety requirements.

c) Provide confidence that the instrument modules will survive the environments imposed during the launch and asscent sequence.

d) Determine operating and performance characteristics from simulated mission environments.

3.3 General Approach

The general approach for attaining the verification program objectives shall be as follows:

a) Several models of Calorimeter Modules shall be built and tested to qualification levels or higher. Each subsequent series shall leverage manufacturability and performance characteristics from the previous model towards the goal of flight production.

b) Verification and test shall begin at the subsystem or component level as required/applicable, prior to delivery for integration to the LAT.

c) Individual Calorimeter Modules shall receive both functional and environmental testing at the qualification or acceptance levels. Flight modules shall either be tested to the acceptance levels. (Reference Table 2. Test Requirements for Calorimeter Modules.)

Table 1. (below) summarizes the requirements for the LAT Calorimeter Modules as taken from the LAT CAL Subsytem Specification – Level IV Specification [LAT-SS-00210-04].

Note: Verification methods are T = Test, A = Analysis, D = Demonstrate, I = Inspect

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
CAL3.06	LAT Energy Range	The CAL shall support LAT calorimetry in the LAT energy range of 20 MeV to 300 GeV.	L	A
CAL3.16	Crystal Energy Range	The energy measurement range for each of the CsI scintillation crystals shall include the range from 5 MeV to 100 GeV.	L	A

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
CAL3.21	Low Energy Resolution	The energy resolution (1 σ) shall be better than 20% (TBR) for normal incidence photons for energies in the 20 to 100 MeV range that interact in the CAL only.	L	A
CAL3.22	Intermediate Energy Resolution	The energy resolution (1 σ) shall be less than 10% for photons for energies in the 100 MeV – 10 GeV range.	L	A
CAL3.26	High Energy Resolution	The energy resolution (1 σ) shall be better than 20% for photons, with on-axis incidence, for energies in the 10 – 300 GeV range.	L	A
CAL3.29	High Energy Resolution, Off Axis	The energy resolution (1 σ) shall be less than 6% for photons, with angles of incidence > 60° off axis, for energies greater than 10 GeV.	L	A
CAL3.34	Crystal Energy Resolution, Carbon	The energy resolution (1 s) shall be less than 2% for high energy (100 to 1000 MeV/nucleon) Carbon ions of normal incidence at a central point in the crystal with beam spot size less than 3 mm diameter.	M	T
CAL3.37	Cosmic Ray Calibration	The CAL shall be capable of energy calibration in orbit using energy depositions from the array of cosmic ray particles.	L	A
CAL3.38	Crystal Relative Calibration	Relative light yield in each crystal shall be determined to better than 3%.	M	T
CAL3.39	Crystal Absolute Calibration	Absolute light yield shall be determined to better than 10%.	M	T
CAL3.44	Depth of Calorimetry	The CAL shall have an active depth of greater than 8.4 radiation lengths of CsI for normally incident particles.	M	I
CAL3.47	Hodoscopic Calorimetry	The CAL module shall be hodoscopic.	M	I
CAL3.50	Active Area	Each CAL module shall provide a projected CsI area of greater than 1050 cm^2 (TBR) for normally incident particles.	M	I
CAL3.53	Passive Material	Passive material in a CAL module (everything not CsI) shall represent no more than 16% of the total mass of the module.	M	I
CAL3.56	Position Resolution	Each layer of the CAL shall position the centroid of a Minimum Ionizing charged particle energy deposition to less than 3.0 cm (1 σ) in all three dimensions for particle incident angles of less than 45° off-axis.	L	T
CAL3.59	Angular Resolution	The single particle angular resolution at 68% containment for the CAL shall be better than 15 x cosθ for cosmic muons traversing all eight layers. (θ is the off-axis angle.)	L	T
CAL3.61	Communication	The CAL electronics shall communicate with the Trigger and Data Flow (T&DF) subsystem using LAT standard communications protocols.	M	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
CAL3.64	Measurement Dead Time	The dead time associated with the capture and measurement of the energy depositions shall be less than 100 μs. The goal is less than 20 μs.	M	T
CAL3.67	Overload Recovery	The CAL electronics shall be capable of recovery from a x1000 overload within 100 μs.	M	T
CAL3.71	Low Energy Trigger Signal	The CAL shall provide a prompt (within 2 ms of an event) low energy trigger signal to the LAT trigger system with a detection efficiency of greater than 90% (TBR) for 1 GeV gamma rays entering the CAL from the LAT field of view with a trajectory which traverses at least 6 radiation lengths of CsI.	L	A
CAL3.74	High Energy Trigger Signal	The CAL shall provide a prompt (within 2 ms of an event) high energy trigger signal with a detection efficiency of greater than 90% for 20 GeV gamma rays entering the CAL from the LAT field of view that deposit at least 10 GeV in the CsI of the CAL.	L	A
CAL3.77	Operating Modes	The CAL shall be capable of operating continuously throughout the orbit.	L	A
CAL3.78	SAA Operations	Operating through traversals of the South Atlantic Anomaly shall not damage the CAL.	L	A
CAL3.97	SAA Operations	Because of the excessive background rates, the acquired data shall not be required to meet performance specifications.	L	A
CAL3.81	Calorimeter Mass	Total mass of the CAL shall not exceed 1440 kg.	L	A
CAL3.85	Calorimeter Power	The power consumption of the CAL system, excluding conditioning, shall not exceed 65 W	L	A
CAL3.88	Environment	The CAL shall be capable of normal operation after being subjected to the environmental conditions given in LAT-SS-00778, LAT Environmental Specification	L	A
CAL3.101	Mission Life Time	The CAL shall maintain the specified performance for a minimum of five years in orbit.	L	A
CAL3.93	Reliability	The reliability of the CAL shall be at least 96% in five years.	L	A
5.1.4	Hodoscopic Calorimetry	The calorimeter shall provide imaging capability or physical segmentation to allow the correlation of events in the tracker with energy depositions in the calorimeter	M	I
5.2.1	Components	The calorimeter subsystem shall consist of a 4 x 4 array of identical modules	M	I
5.2.2	Mounting	The calorimeter modules shall be mounted inside the grid matrix of the LAT GRID subsystem	M	I
5.2.3	Structure	The base of the calorimeter modules shall support the mechanical, thermal and electrical interfaces of the LAT T&DF, ACD and power system components	M	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
5.2.4	Hodoscopic	The calorimeter modules shall be hodoscopic arrays of CsI(Tl) scintillation crystals: eight (8) layers of twelve (12) CsI(Tl) scintillation crystals	M	I
5.2.5	PIN Photodiodes	PIN photodiodes shall view each end of the CsI scintillation crystals for measurement of the energy depositions in the crystals	M	I
5.2.6	Crystals	The CsI crystals shall be processed such that the measurements by the PIN photodiodes at the ends of a crystal provide a measurement of the longitudinal position of the energy deposition in the crystal	M	I
5.2.7	Electronics	Each calorimeter module shall include analog and digital readout electronics (AFEE) on the four vertical faces at the ends of the CsI crystal array	M	I
5.3.1	Module Components	The major components of a calorimeter module shall be a mechanical structure, an array of ninety-six CsI(Tl) detector elements and four analog front end electronics (AFEE) printed wire assemblies	M	I
5.3.2	Module Geometric Area	Each calorimeter module shall provide a projected CsI area of greater than 1000 cm2 for normally incident particles.	M	I
5.3.3	Module Mass	The mass of each calorimeter module shall not exceed 93.25 kg.	M	T
5.3.4	Module Power	The power consumption of each calorimeter module, excluding conditioning, shall not exceed 5.6875 W.	M	T
5.3.5.2	Data Format	Serial data from the readout electronics shall be merged into a serial message by a tower electronics module (TEM) mounted on the base plate of each module for transfer to the T&DF subsystem	M	I
5.3.5.3	Data Collection	The TEM shall process trigger requests and collect rate and housekeeping monitoring from the CAL AFEE and distribute commands from the T&DF to the AFEE.	M	I
5.4.1.2	Division of Single Crystal Energy Measurement	The full range of energy measurement in each crystal shall be divided into four sub-ranges, each with approximately one eighth of the dynamic range of the previous. The highest energy range (“HEX1”) shall span up to the full energy range, nominally 100 GeV. The next highest energy range (“HEX8”) shall span up to ~1/8th of the full range, up to ~12.5 GeV. The next energy range (“LEX1”) shall span up to ~1/64th of the full range, i.e. up to ~1.6 GeV. The lowest energy range (“LEX8”) shall span up to ~1/512th of the full range, i.e. up to ~200 MeV	M	T
5.4.1.3	Energy Measurement, Integral Linearity	In each of the four energy ranges (LEX8, LEX1, HEX8, and HEX1), the maximum deviation from a linear transfer function between charge injection amplitude and ADC output shall be <1% of full scale.	M	T

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
5.4.1.4	Energy Measurement, Peaking Time	The LEX8 signal shall peak at 3.5 ± 1 μs at 20–25C. All LEX8 channels on a single AFEE board shall have the same peaking time ±1 μs at 20–25 C.	M	T
5.4.1.5	Energy Measurement, Gain Settings	The low energy and high energy gains shall be adjustable over a range of at least a factor of two in eight monotonically increasing steps.	M	T
5.4.1.6	Energy Range Selection	Energy range selection logic shall control which of the four energy measurements made at each CDE end face is selected for inclusion in the event readout. Selection shall be independently determined for each CDE end face. Selection of one or all four ranges shall be permitted. Range selection discriminators shall test the output of the four ranges to determine which of the ranges have been saturated by the energy deposition in the crystal. Two modes of selection shall be implemented, auto range selection and commanded range selection. In auto range selection mode, the range selection discriminators shall be tested to select the lowest energy range that is not saturated. In commanded range selection, a range selected by command input shall be presented	M	T
5.4.1.7	Energy Measurement, Range Droop	The range readout order shall not affect the digitized signal amplitude: for a given charge-injection pulse amplitude, the digitized output for any range shall be constant to within 1%, regardless of whether it is read out first or last.	M	T
5.4.1.8	Zero Suppression	The signal from each CDE end face shall be compared with a programmable threshold to identify CsI crystals with measurable energy depositions. The zero suppression level shall be adjustable by command over a range at least as broad as from one pedestal-rms above pedestal to 100 LEX8 ADC bins above pedestal	M	T
5.4.2.1	Pedestal Noise	The rms width of the pedestal distribution in each of the four energy ranges of each CDE in a Module shall not exceed the limits in Table 1 of the Level IV Spec. This measurement shall be made at the nominal gain setting only.	M	T
5.4.2.2	Pedestal Centroid	The pedestal centroid shall not exceed 1000 ADC bins in any of the four energy ranges at any gain setting.	M	T
5.4.3.2	Low Energy Trigger Enable/Disable	The low-energy trigger shall be individually enabled or disabled for each CDE end face by command input	M	T
5.4.3.3	Low Energy Trigger Energy Range	The low energy trigger level shall be individually adjustable by command input. The range of adjustment shall span 50 MeV to 125 MeV. For ground test, at least 90% of GCFEs in a given CAL Module shall allow the low-energy trigger to be set to at least one level between 4 MeV and 12 MeV (the typical cosmic muon energy deposition in a CDE).	M	T

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
5.4.3.5	High Energy Trigger Enable/Disable	The high-energy trigger shall be individually enabled or disabled for each crystal end by command input	M	T
5.4.3.6	High Energy Trigger Energy Range	The high energy trigger discriminator level shall be individually adjustable by command input to DACs inside the ASIC. The range of adjustment shall span the range from 500 MeV to 2.5 GeV	M	T
5.5	Environmental	The CAL shall be capable of normal operation after being subjected to the environmental conditions given in LAT-SS-00778	M	T
5.5.1	EMC/EMI	The CAL Module shall be subject to EMC/EMI testing in compliance with levels and configurations specified in LAT-SS-00778	M	T
5.5.2	Vibration	The CAL Module shall be subject to vibration testing in compliance with levels and configurations specified in LAT-SS-00778	M	T
5.5.3	Thermal-Vacuum	The CAL Module shall be subject to thermal-vacuum testing in compliance with levels and configurations specified in LAT-SS-00778	M	T
5.5.4	Component Environment	The CAL components shall be designed to operate in a low Earth orbit environment	M	A
5.5.5	Sub-System Environment	The CAL shall be designed to operate in a low Earth orbit environment	M	A
5.5.6	SEE Immunity	Critical systems shall be immune to SEEs. Critical systems are those that can cause permanent loss of mission in the event of a single failure	M	A
5.5.7	Minimum Power Up Temperature	All electronics shall be able to power up from an initial temperature of –30C and subsequently transition into their other operational modes/states	M	T
6.1.1	Module Contents	Each calorimeter module shall contain 96 CDEs	M	I
6.1.2	Crystal	The CDE shall contain a CsI(Tl) crystal shaped as a rectangular parallelepiped with beveled edges and its surfaces treated to control scintillation light yield at the two ends.	C	I
6.1.3	Wrap	The CDE shall contain an optical wrap surrounding the CsI crystal to provide the required optical performance.	C	I
6.1.4	Dual Photodiode	The CDE shall have a dual PIN photodiode assembly bonded to each end of the CsI crystal	C	I
6.1.5	Interconnect	Two multi-strand wire pairs shall be attached to each PIN photodiode to provide electrical connections with the analog front end electronics board (AFEE).	C	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
6.2.1	Large Diode Light Yield	The light yield measured by the large PIN photodiode shall be greater than 5000 e-/MeV for energy depositions at the center of the CsI crystal (at time of CDE assembly, room temperature (20 – 25 deg C), measurement techniques as specified in LAT-PS-02571).	C	T
6.2.2	Small Diode Light Yield	The light yield measured by the small PIN photodiode shall be greater than 800 e-/MeV for energy depositions at the center of the CsI crystal (at time of CDE assembly, room temperature (20-25 deg C), measurement techniques as specified in LAT-PS-02571).	C	T
6.2.3	Light Asymmetry with PIN Photodiodes	The change in light asymmetry measure shall be between 0.25 and 0.70 for energy depositions centered at two locations symmetrically placed on the crystal, each 12 cm from the center of the crystal. The asymmetry measure is defined as the ratio (P-M) / (P+M), where P = signal in large diode at the "plus" end and M = signal in large diode at "minus" end.	C	T
6.2.4	Surface Treatment	The crystal end faces shall be roughened in a random pattern to increase the strength of the bond with the photodiode assembly. The long faces shall be treated to achieve the light asymmetry specification with the specified wrapping technique.	C	I
6.2.5	Wrapping Technique	The crystal shall be wrapped with VM 2000 reflective film. The wrap shall be sufficiently tight that the completed CDE can be inserted into its cell within the mechanical structure. The wrap shall not extend past the ends of the crystal, so that it does not interfere with the positioning of the CDE within its cell. The ends of the crystal shall not be covered with the wrap.	C	I
6.2.6	Temperature Effects on Optical Performance	The CDE shall meet requirements after exposure to the qualification temperature range.	C	T
6.2.7	CDE Spatial Resolution of Energy Deposition	The CDE shall be capable of positioning a Minimum Ionizing energy deposition to less than 1.5 cm (1 σ).	C	A
6.3.1	Crystal Geometry	The CsI (Tl) crystals shall be rectangular parallelopipeds with a chamfer on the edges of the long dimension. Figure 1 of LAT-DS-00096 shows the mechanical configuration and tolerances for the crystals.	C	I
6.3.2	Dimensions	Overall dimensions (mm) of the CsI crystals at 20° C shall be: length: 326.0 mm, height: 19.9 mm, Width: 26.7 mm. The tolerance on dimensions (mm) shall be: Length: +0.0, –0.6 mm, Height and Width: +0.0, –0.4 mm	C	T

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
6.3.3	Chamfer	The four 326 mm edges of the crystal shall have a chamfer. Chamfer length: 0.7 mm, tolerance ±0.20. Chamfer angle: 45°, tolerance ±5	C	T
6.3.4	Light Yield Tapering	The CsI crystals shall be processed so that the scintillation light is tapered with position. The tapering shall be monotonic along the crystal and such that with the source 2 cm from one end the light collected at the far end is 60 ± 10 % of the light collected by the PMT close to the source. The tapering shall be determined using PMTs exposed to the full crystal end faces	C	T
6.3.5	Radiation Hardness	Radiation environment (total radiation dose) shall not reduce light output from the CsI crystals by more than 50% at EOL. After radiation with 10 krad gamma-rays from a Cobalt-60 source, the light yield shall not be reduced by more than 50%.	C	T
6.4.3	Photo Sensitivity	The photodiodes shall have photo sensitivity greater than 0.33 A/W at 540 nm.	C	I
6.4.4	Dark Current	The photodiodes shall have dark current of less than 10 nA for the large diode and 3.0 nA for the small diode at 20C	C	I
6.4.5	Terminal Capacitance	The photodiodes shall have terminal capacitance of less than 100 pF for the large diode and 15 pF for the small diode at 1 MHz with 70 V reverse bias	C	I
6.4.6	Physical Dimensions	The photodiode carrier shall be 21.3 mm x 14.0 mm x 1.8 mm	C	I
6.4.7	Active Areas	The small PIN photodiode shall have active area greater than 25 mm^2. The large PIN photodiode shall have active area greater than 150 mm^2.	C	I
7.1.1	Geometry	The calorimeter module shall comply with the geometry specified in Table 1. The total height of the calorimeter and its mechanical mounting structure shall not exceed 223.8 mm	M	T
7.1.2	Mechanical Interfaces	The CAL module structure shall provide the mechanical interface to the LAT grid as specified in ICD LAT-SS-00238 and LAT-DS-00233. The CAL module structure shall provide the nominal positioning, support and mounting interfaces for all subsystem components. The CAL module structure shall support the Power Supply module and TEM as specified in LAT-DS-00233.	M	I
7.1.3	Venting Requirements	In compliance with LAT-SS-00238, the CAL structure shall vent downward, past the bottom plate, not up into the volume between the TKR and the CAL	M	I
7.1.4	Purging Requirements	Purging with dry nitrogen shall be required if the relative humidity of the environment exceeds 50% for 3 hours, or immediately if the RH exceeds 55%.	M	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
7.2	CAL Module Structural Requirements	The CAL structure shall provide and maintain the positional integrity of all components that it supports. The structure shall maintain the operational stability of the positions of all instrument components under load	M	I
7.2.1	Structural Stiffness	The CAL structure baseplate is integral to the strength and stability of the LAT GRID. The mechanical structure shall provide a minimum fundamental frequency greater than 100 Hz to a CAL module, isolated from other systems	M	T
7.2.2.1	Distortion Under Static Load	The CAL mechanical structure shall be able to withstand the different load events without yielding, failing or exhibiting deformations that can influence the performance of the CAL modules or any other system or sub-system. Any point of the mechanical structure shall not displace by more than 0.5mm under a +/-12 g static load, applied along X or Y axis independently, to avoid interaction with the grid walls. Any point of the top of the mechanical structure shall not displace by more than 0.5 mm under a +/- 12 g static load applied along Z axis. To minimize mechanical loads on the TEM boxes, attached below the CAL modules, no point of the bottom plate of the mechanical structure shall displace by more than 0.5mm under a +/- 12 g static load applied along the Z axis.	M	A
7.2.2.2	Distortion Under Dynamic Load	The CAL mechanical structure shall be stiff enough in the X and Y directions to keep the difference between the RMS displacements between any two points of the side panels below 0.25 mm, under random vibration with qualification levels. The mechanical structure shall be stiff enough in the Z direction to keep the difference between the RMS displacements between any two points of the top of the structure below 0.5 mm, under random Vibration with qualification levels. The mechanical structure shall be stiff enough in the Z direction to keep the difference between the RMS displacements between any two points of the bottom plate below 0.25 mm, under random vibration with qualification levels. The levels for random vibration are defined in LAT-SS-00778	M	A
7.2.2.3	Distortion Under Thermal Load	Over a temperature change of 10 degrees C, the mechanical structure shall not distort more than: 0.25 mm between any two points of the side panels, 0.5 mm between any two points of the top of the structure, 0.25 mm between any two points of the bottom plate.	M	A

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
8.2	Temperature Monitoring	The temperature of each AFEE board shall be monitored by a sensor with an accuracy of ± 0.5C. The temperature of the top plate and bottom plate of the calorimeter shall also be monitored by separate temperature sensors with the same accuracy. There shall therefore be 6 sensors per calorimeter module, or 96 sensors for the entire calorimeter.	M	I
9.1	GCFE	The basic functions of the GCFE include charge-sensitive amplification, shaping, multi-range post-amplification, trigger function, track & hold function, and auto-range selection. The key challenges for the ASIC are the large dynamic range and low power dissipation. The GCFE shall perform spectroscopic measurements over a range from 0.4 MeV to 100 GeV. Each GCFE ASIC shall service one crystal end. The dynamic range shall be divided into two independent signal chains, one for the low energy range, and one for the high energy range	C	I
9.1.1	Signal Characteristics	The maximum charge delivered to the input of the GCFE ASIC in each gain range shall comply with the table in the Level IV Spec under the assumption of the nominal values for light yield in the photodiodes and amplifier ranges.	C	I
9.1.2.1	Low Energy Range	A large area (~150 mm2) PIN photodiode provides the input signal for the low energy range charge amplifier. The low energy charge amplifier shall process energy depositions in the 2 MeV to 1.6 GeV range. The characteristics of the inputs to the low energy range are summarized in Table 3.	C	I
9.1.2.2	Low Energy Charge Sensitivity	The low energy range amplifier shall be designed to receive a charge of ~ 5000 e–/MeV (with time constants defined by CsI(Tl) scintillation constants	C	I
9.1.2.3	Low Energy Input Capacitance	The low energy charge amplifier shall meet performance specs when attached to PIN photodiode with capacitance < 100 pF. Performance may be different when the photodiode is not attached.	M	T
9.1.2.4	Low Energy Input Dark Current	The low energy charge amplifier shall meet performance specs when attached to PIN photodiode with dark or leakage current < 10 nA at a temperature of 20C. Performance may be different when the photodiode is not attached	M	T
9.1.2.5	Low Energy Overload Recovery	The low energy front end shall recover from a x1000 overload within 500 msec. Recovery is defined as signal amplitude below the accept or zero-suppression threshold.	C	T
9.1.2.6	Low Energy Gain Adjust	The gain of the low energy channels shall be adjustable by at least a factor of 2 in monotonically increasing steps	C	T

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
9.1.3.1	High Energy Range	A smaller area (~25 mm2) PIN photodiode provides the input signal for the high energy range charge amplifier. The high energy charge amplifier shall process energy depositions in the 100 MeV to 100 GeV range. The characteristics of the inputs to the high energy range are summarized in Table 3 in the Level IV Spec.	C	I
9.1.3.2	High Energy Charge Sensitivity	The high energy range amplifier shall be designed to receive a charge of ~ 800 e–/MeV with time constants defined by CsI(Tl) scintillation constants. These are identified in Table 9.4 of the Level IV Spec.	C	I
9.1.3.3	High Energy Input Capacitance	The high energy charge amplifier shall meet performance specs when attached to PIN photodiode with capacitance < 15 pF. Performance may be different when the photodiode is not attached.	M	T
9.1.3.4	High Energy Input Dark Current	The high energy charge amplifier shall meet performance specs when attached to PIN photodiode with dark or leakage current < 3 nA at a temperature of 20C. Performance may be different when the photodiode is not attached.	M	T
9.1.3.5	High Energy Gain Adjust	The gain of the high energy channels shall be adjustable by at least a factor of 2 in monotonically increasing steps. An additional gain setting shall be used for ground aliveness testing	C	T
9.1.4	Shaping Amplifiers	The outputs of the charge sensitive preamps shall be shaped with two differing time constants: fast shaping for trigger discriminators and slower shaping for energy measurements. The slow shaped signals of each charge amplifier are each divided into two energy domains.	C	I
9.1.4.1	Low Energy Fast Shaper (FLE) Peaking	The low energy fast shaped signals shall peak at 0.5 ± 0.2 msec.	C	I
9.1.4.2	Low Energy Fast Shaper Energy Range	The low energy fast shaping amplifier shall support the lowest ~25% of low energy range, i.e. nominally 400 MeV	C	I
9.1.4.3	High Energy Fast Shaper (FHE) Peaking	The high energy fast shaped signals shall peak at 0.5 ± 0.2 msec.	C	I
9.1.4.4	High Energy Fast Shaper Energy Range	The high energy fast shaping amplifier shall support the entire low energy range, i.e. nominally 100 GeV maximum energy.	C	I
9.1.4.5	Low Energy Slow Shapers (SLE) Peaking	The low energy slow shaped signals shall peak at 3.5 ± 1 msec at 20–25C. All ASICs shall have the same peaking time ±1 msec at 20–25 C.	C	T
9.1.4.6	Low Energy X1 (LEX1) Amplifier	The LEX1 amplifier of the low energy channel shall process the entire low energy charge amplifier range.	C	T

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
9.1.4.7	Low Energy X8 (LEX8) Amplifier	The LEX8 amplifier of the low energy channel shall process the lowest eighth of the low energy charge amplifier range.	C	T
9.1.4.8	High Energy X1 (HEX1) Amplifier	The HEX1 amplifier of the high energy channel shall process the entire high energy charge amplifier range.	C	T
9.1.4.9	High Energy X8 (HEX8) Amplifier	The HEX8 amplifier of the high energy channel shall process the lowest eighth of the high energy charge amplifier range.	C	T
9.1.5	Track & Hold	Each of the four slow shaped amplifiers (LEX8, LEX1, HEX8, HEX1) shall have track and hold (T&H) circuits designed to hold the peak amplitude of the shaped outputs for amplitude measurements using external ADCs. The timing of the hold signal to capture the peak shall be controlled externally.	C	I
9.1.5.1	T&H Tracking	When the hold signal is not active, the T&H circuit shall track the amplitude of the shaped input signal. Thus, adjustment of the hold signal timing relative to the energy deposition shall permit mapping of the pulse shape of the shaper output.	C	I
9.1.5.2	T&H Hold	The T&H circuit shall respond to an externally generated hold signal by capturing the amplitude of the shaped signal at the time of the hold. Hold aperture time shall be less than 50 nsec.	C	I
9.1.5.3	T&H Droop	The T&H circuit shall be capable of holding a constant signal amplitude for >60 msec with less than 0.5% droop for a signal amplitude dynamic range of 500.	C	T
9.1.6	Non-Linearity	In each of the four ranges (LEX8, LEX1, HEX8, and HEX1) the maximum deviation from a linear model shall be <1%.	C	T
9.1.7	Analog Multiplexer	An analog multiplexer shall present one of the four T&H signals to an output buffer for external amplitude measurements with an ADC. The analog multiplexer shall be controlled by energy range selection logic as described in 9.1.7 of the Level IV Spec.	C	I
9.1.8	Output Buffer	An output buffer shall accept the output of the analog multiplexer and drive the load of an external ADC.	C	I
9.1.8.1	Output Buffer Range Adjust	The external buffer shall adjust the voltage range of the analog multiplexer to match the input voltage range of the external ADC.	C	I
9.1.9	Energy Range Selection	Energy range selection logic shall control which of the four T&H energy ranges is selected in the analog multiplexer and presented to the output for digitization by the ADC.	C	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
9.1.9.1	Range Selection Discriminators	Range selection discriminators shall test the output of the four T&H ranges to determine which of the ranges have been saturated by the energy deposition in the crystal. Saturation is defined as the amplitude at which the input signal enters a non-linear region.	C	I
9.1.9.2	Range Selection Readout	The results of the range selection logic, i.e. the multiplexer setting, shall be transmitted to external logic for inclusion in the event readout with the associated ADC value.	C	I
9.1.9.3	Auto Range Selection	In auto range selection mode, the range selection discriminators shall be tested to select the T&H output with the lowest energy range (highest gain) that is not saturated and set the analog multiplexer to this T&H output.	C	I
9.1.9.4	Commanded Range Selection	In commanded range selection, the selection logic shall use a pre-loaded (via command input) range and set the multiplexer to that T&H output.	C	I
9.1.9.5	Sequential Range Selection	In either the auto range or commanded range selection mode, it shall be possible to sample all four T&H outputs in sequence. The sequence shall start at the autoranged or commanded range and increment (modulo 4) through the four ranges. The increasing order shall be LEX8, LEX1, HEX8 and HEX1.	C	I
9.1.10.1	Accept Discriminator	The amplitude of the LEX8 output shall be compared with a programmable threshold – the accept lower level discriminator – to identify CsI crystals with measureable energy depositions. This crystal-accept signal shall be transmitted to external logic for determination of crystals to be included in the event readout message.	C	I
9.1.10.2	Accept Discriminator Adjustment	The outputs of the two 0.5 msec shaping amplifiers (FHE and FLE) are connected to discriminators. The two outputs of the trigger discriminator logic are provided to external logic which forms the calorimeter trigger request inputs to the GLAST trigger system.	C	T
9.1.11	Trigger Discriminator and Logic	The outputs of the two 0.5 msec shaping amplifiers (FHE and FLE) are connected to discriminators. The two outputs of the trigger discriminator logic are provided to external logic which forms the calorimeter trigger request inputs to the GLAST trigger system.	C	I
9.1.11.1	Trigger Jitter	The variation in time of the leading edge of the trigger output from the time of energy deposition shall be less than ± 0.2 msec.	C	T
9.1.11.2	Trigger Enables	Each of the two trigger signals shall be individually enabled or disabled by command input to the ASIC.	C	T

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
9.1.11.3	Low Energy Trigger Discriminator Adjustment	The low energy trigger (FLE) discriminator level shall be adjustable by command input to DACs inside the ASIC. Two adjustment ranges shall be provided: lowest energies (<30 MeV) with <5 MeV step size and moderate energies (<200 MeV) with <15 MeV step size.	C	T
9.1.11.4	High Energy Trigger Discriminator Adjustment	The high energy trigger discriminator level shall be individually adjustable by command input to DACs inside the ASIC. The range of adjustment shall span the range from 500 MeV to 2.5 GeV.	C	T
9.1.12	Calibration System	The GCFE ASIC shall accept a precision calibration voltage from an external DAC as a reference voltage for a calibration charge injection system	C	I
9.1.12.1	Calibration Range	The test charge injection system shall be capable of testing the entire dynamic range of the GCFE ASIC.	C	I
9.1.12.2	Charge Shaping	The charge injection system shall provide input signals to the charge amplifier with time characteristics similar to the CsI light collection.	C	I
9.1.12.3	Charge Injection	External signals shall cause the injection of charge into the charge amplifiers. Commandable configuration logic shall cause the injection to occur into either or both of the low energy and high energy charge amplifiers.	C	I
9.1.12.4	Test Gain on High Energy Charge Amplifier	The high energy charge amplifier shall provide a test gain to be used in ground aliveness tests with cosmic muons. The test gain shall increase the nominal gain by a factor of approximately 10. The test gain configuration is pre-selected by command input to the ASIC.	C	I
9.1.13	Configuration Control	The GCFE ASIC operating configuration shall be selected by commands received via serial command system that is compatible with GLAST standard command protocols.	C	I
9.1.13.1	Command Address	Each GCFE ASIC shall respond to its own command address, which shall be programmed via input address pins.	C	I
9.1.13.2	Command Functions	The GCFE shall decode and recognize predefined command functions and internally route associated command function data to the appropriate configuration register.	C	I
9.1.13.3	Configuration Readback	The GCFE shall be capable of reporting its operating configuration to the external data system when requested via configuration readback command requests.	C	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
9.1.14	Signal Acquisition Control	The GCFE ASIC shall capture and readout event amplitudes under the control of an external acquisition control timing signal. The external timing shall control the capture of the peak pulse amplitude in the T&Hs, the range selection and readout of the range and crystal accept bits, the selection and readout of sequential ranges, and the final reset of the ASIC to idle, tracking configuration. The timing of this sequence shall be controlled with the external signal; the control logic and decision making shall be internal to the ASIC.	C	I
9.1.15.1	Low Energy Equivalent Noise	The equivalent noise (RMS) on the low energy slow shaped signal paths (LEX8, LEX1) shall be less than 2000 e–. The equivalent noise (RMS) on the low energy fast shaped signal path (FLE) shall be less than 3000 e–.	C	T
9.1.15.2	High Energy Equivalent Noise	The equivalent noise (RMS) on the high energy slow shaped signal paths (HEX8, HEX1) shall be less than 2000 e–. The equivalent noise (RMS) on the high energy fast shaped signal path (FHE) shall be less than 10000 e–.□	C	T
9.1.15.3	Integral Linearity	The output of the buffer amplifier for each of the four amplifier ranges shall be monotonically increasing with charge input over the top 99.9% of the energy range. The integral non-linearity shall be less than ±0.5% of full scale. This is the deviation of the best fit straight line from the measured amplitudes over the top 99% of the energy range.	C	T
9.1.15.4	Single Range Processing Deadtime	The signal acquisition and processing time for a single energy range shall be less than 100 msec. The goal shall be 20	C	T
9.1.16.1	Operating Temperature Range	The performance specifications of the GCFE ASIC shall be achieved over the operational temperature ran	C	T
9.1.16.2	Storage Temperature Range	The GCFE ASIC shall be capable of meeting its performance specifications after indefinite storage in the temperature range.	C	A
9.1.16.3	Qualification Temperature Range	The performance of the ASIC shall be tested over the qualification temperature range of –30 to +50 degrees C. It shall survive testing over this range and meet performance specifications when returned to the operational temperature range.	C	T
9.1.16.4	Radiation Single Event Latchup	The GCFE ASIC shall be insensitive to latchup for LETs < 8 MeV/(mg/cm2).	C	T
9.1.16.5	Radiation Total Dose	The GCFE ASIC shall meet its performance specifications after a total radiation dose of 10 kRad.	C	T
9.1.17.1	Mounting	The GCFE ASIC shall be mounted in a quad flatpack carrier with square footprint	C	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
9.1.17.2	Height	The GCFE carrier height shall be less than or equal to 3 mm	C	I
9.1.18	Power	The GCFE ASIC power consumption shall be less than 6 mW per CsI crystal end	C	T
9.2.1	Number of Bits	The ADC shall be a 12 bit ADC	C	I
9.2.2	Differential Non-Linearity	The average differential non-linearity of the ADC shall be less than 0.25 least significant bit	C	I
9.2.3	Integral Non-Linearity	The maximum non-linearity of the ADC shall be 0.5 % of full range.	C	I
9.2.4	Speed	The ADC shall perform a full conversion in less than 10 microseconds for all input values.	C	I
9.2.5	Input Voltage Range	The ADC shall convert signals between 0 and an applied reference voltage. The applied reference voltage shall be between 2.0 and 3.0 Volts.	C	I
9.2.6	Power	The ADC shall use less than 5 mW in quiescent mode and less than 8 mW during conversions	C	I
9.2.7	Mechanical Dimensions	The ADC shall not be taller than 3 mm, and its footprint shall be less than 13mm by 13 mm.	C	I
9.2.8	ADC Power Voltage	The ADC shall operate at a voltage of 3.3 Volts.	C	I
9.3.1	Functionality	The GCRC shall have functionality to communicate with the Tower Electronics Module and all components requiring communicate on one AFEE board row, consisting of GCFE ASICs, ADCs, and DAC	C	I
9.3.2	Power Consumption	The GCRC ASIC shall consume less than 80 mW when operated at 3.3 Volts	C	T
9.4.1	Functionality	Each board shall hold the GCFEs, ADCs, GCRCs, a DAC (digital to analog converter, for calibrations), a temperature sensor and all these components' associated electronics. The AFEE boards shall also support whatever additional electronics or sensors are deemed necessary in the location of the AFEE boards.	C	I
9.4.2	Types of AFEE Boards	There shall be two types of AFEE boards, named X boards and Y boards, for the direction of the crystals they service. The two X (Y) boards are then separated in to a –X (–Y) and + X (+Y) board, depending on which side of the calorimeter they service.	C	I
9.4.3	Channel Numbers and Layout	Each AFEE board shall service 48 crystal ends. These crystal ends are arranged in 4 layers of 12 crystals. The crystal pitch is ~ 28 mm, the layer pitch is ~ 42 mm. The AFEE layout shall minimize the connection distance between the PIN diode and the GCFE.	C	I
9.4.4	PIN Diode Interface	Each crystal end shall connect to the GCFE with two pairs of multi-strand wire fed through a hole in the AFEE board.	C	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
9.4.5	Operating Voltages	Each AFEE board is provided with two voltages: one 3.3V voltage to operate the AFEE board itself, and one high voltage in the negative 50-90 volt range to bias the PIN diodes. The regulations of these voltages shall not happen on these boards, but the boards shall filter these voltages appropriately.	C	I
9.4.6	TEM Electrical Interfaces	The AFEE board shall communicate to the Tower Electronics Module (TEM) through Low Voltage Differential Signaling (LVDS). No common ground shall span the connection.	C	I
9.4.7	Mechanical Dimensions	Each AFEE board shall have maximum dimensions of 341 mm by 341 mm. The maximum thickness of the board shall be 2 mm. The maximum thickness of the board and its components shall be 8 mm. No component shall be raised more than 3 mm from either surface of the board.	C	I
9.4.8	Mechanical Interfaces	The mechanical interface and support for each X-side (Y-side) AFEE board shall be compatible with the X-side (Y-side) Closeout Panel, as specified in LAT-DS-00920 (LAT-DS-00921).	C	I
9.4.9	Power	Each AFEE board shall not use more than 1.25 Watts of the 3.3V voltage line. Each AFEE board shall not use more than 0.001 Watts of the 50-90 V voltage line.	C	T
9.4.10.1	Operating Temperature Range	The performance specifications of the AFEE shall be achieved over the operational temperature range given in Table 2.	C	T
9.4.10.2	Storage Temperature Range	The AFEE shall be capable meeting its performance specifications after indefinite storage in the temperature range of –20 to +40 degrees C.	C	A
9.4.10.3	Qualification Temperature Range	The performance of the AFEE shall be tested over the qualification temperature range given in Table 2. It shall survive testing over this range and meet performance specifications when returned to the operational temperature range.	C	T
9.4.11	Grounding	The AFEE board shall be grounded to the calorimeter structure per LAT document LAT-SS-00272-D1, LAT Grounding and Shielding Plan.	C	I
9.4.12	AFEE Failure	Each AFEE board shall be constructed such that an electrical or electronic failure of one board does not affect any of the other three boards of the same calorimeter module, or the two provided voltages.	C	I
9.4.13	Coating	Each AFEE board shall be coated with conformal coating per specification TBD.	C	I
9.5	CAL Module to T&DF Interface	The AFEE shall interface to the T&DF system using wire bundles that attach the AFEE to the TEM mounted on the CAL baseplate.	C	I

Reqmt Number	Requirement Name	Description	Verif Level	Verif Method
10	Data System	The Calorimeter Data System functionality shall reside in the Calorimeter Controller, located in the Tower Electronics Module.	C	I
11	Operational Modes	The Calorimeter shall provide the functionality required for the SI to perform operations in the sky survey, pointed observation and safe modes of operation. These specific requirements can be found in the GLAST Mission System Specification (MSS), Section 3.1.15, Modes of Operation. The Calorimeter shall meet the load shedding requirements of the fault protection functions on the spacecraft that are identified in the SI/SC IRD, Section 3.2.7, Fault Protection.	C	I
12.1	Stand-Alone Testing	CAL modules shall have ground-support equipment that will allow for stand-alone operation, test and data analysis.	M	I
12.2	Simulators	CAL module GSE shall be supported by TEM and T&DF simulators provided by the T&DF subsystem designers.	M	I
12.3	Computer and Network	Workstations or personal computers associated and provided with the CAL subsystem shall have Ethernet connectivity with appropriate software to share data files and electronic messages with other nodes on the I&T local area network	M	I
12.4	Pre-Integration Testing	All module components shall undergo functional, environmental and interface testing prior to module integration and test in order to verify their individual functional and performance requirements	M	A
13.1	Integration and Test Temperature Range	The Calorimeter shall be capable of tolerating temperatures of 20-25oC in air, in any operational mode. This is the expected temperature range of the controlled environment in the integration and test facilities.	M	A
13.2	Integration and Test Relative Humidity	The Calorimeter shall be capable of tolerating relative humidity in the range 35%-50%, in any operational mode. This is the expected humidity range of the controlled environment in the integration and test facilities.	M	A

Table 1: Calorimeter requirements verification matrix

Note: Verification methods are T = Test, A = Analysis, D = Demonstrate, I = Inspect

HARDWARE						MECHANICAL							ELECTRICAL					THERMAL				OTHER					
MODEL	LEVEL	COMPONENT (ITEM)	QUANTITY	TYPE	SUPPLIER	STATIC LOAD	SINE BURST	SINE SWEEP	RANDOM VIB	ACOUSTIC	PRESSURE PROFILE	MASS PROPERTIES	INTERFACE VERIFICATION	EMC/EMI	ESD COMPATABILITY (GRD)	MAGNETICS	FUNCTIONAL	THERMAL VACUUM	THERMAL BALANCE	THERMAL CYCLE	HUMIDITY	RADIATION	BAKEOUT	BEAM TEST-EM SHOWERS	BEAM TEST-HADRONS	BEAM TEST - HEAVY IONS	COMMENTS
	C	VM2 CsI Det Elements (CDE)	12	Q	F	A			A			M	T	A	A	A	T	TQ		TQ		T					
	C	VM2 PreElect Modules (PEM)	1	Q	F	T	TQ	TQ	TQ		TQ	M	T				T	TQ		TQ							
	C	VM Electronics Prototype	1	Q	N												T										
ENGINEERING	C	EM CsI Det Elements (CDE)		Q	F/N							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	EM Composite Structure	1	Q	F		TQ		TQ			M											A				
	C	EM Front End Elect (AFEE)	4	Q	N	A	A	A	A			M	T	A	A		T			TQ	M	A					
	S	**EM CAL Module**	1	Q	N		TQ	TQ	TQ		A	M	T	T	T		T	TQ	TQ	TQ	M	A	A	T	T	T	
STRUCTURAL	S	**SM CAL Module**	1	Q	F		TQ		TQ			M											A				Structural Model
	S	**SFM CAL Module**	1	Q	F		TQ		TQ			M											A				Structural Flight Model
QUALIFICATION	C	QM CsI Det Elements (CDE)	96	Q	F							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	QM Composite Structure	1	Q	F		TQ		TQ			M															
	C	QM Front End Elect (AFEE)	4	Q	N	A	A	A	A			M	T	A	A		T			TQ	M	A					
	S	**QM CAL Module**	1	Q	N		TQ	TQ	TQ		A	M	T	T	T		T	TQ	TQ		M	A	M				
FLIGHT	C	FM CsI Det Elements (CDE)	1632	F	N							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	FM Composite Structure	17	F	F		TQ		TQ			M															
	C	FM Front End Elect (AFEE)	68	F	N	QS	QS	QS	QS			M	T	QS	QS		T			TQ	M	A					
	S	**FM CAL Module**	17	F	N		QS	TA	TA		QS	M	T	QS	QS		T	TA			M	A	M				

LEVEL OF ASSEMBLY:
S = Subsystem
C = Component

SUPPLIER:
F = France
N = NRL

UNIT TYPE:
PR = ProtoFlight
F = Flight
S = Spare
Q = Qualification Unit

VERIFICATION METHOD:
T = Test
A = Analysis
M = Measurement
I = Inspection
TQ = Test, Qual. Level
QS = Qual by Similarity
TA = Test, Acceptance Level

Table 2: Calorimeter Verification Matrix

3.4 Verification Methods

Verification methods for each of the performance requirements specified in the CAL Subsystem Level IV Specification, [LAT-SS-00210]. As specified, requirement verification may include analysis, inspection, or demonstration as well as environmental, functional, and performance testing.

3.4.1 Verification Method Definitions

a) Analysis – A verification method utilizing techniques and tools such as analytical assessments, simulations, models, or prior test data.

b) Inspection – A method of verifying physical characteristics without the use of special laboratory or test equipment, procedures, test support items, or services. Standard methods such as visual gauges, etc. are used to verify compliance with the requirements. Inspection also includes the review of design documentation, material lists, code, plans, etc.

c) Demonstration – A qualitative method of verification that evaluates the properties of the subject equipment by observation. It may be used with or without special test equipment or instrumentation to verify required characteristics such as functioning human engineering features, accessibility, transportability, or displayed data.

d) Test – A quantitative method of verification wherein performance requirements are verified by measurement during and after the controlled application of functional and environmental stimuli. These measurements usually require the use of special test equipment recorded data, procedures, laboratory equipment, or services.

4 GENERAL INFORMATION AND REQUIREMENTS

4.1 Test Facility Requirements

The facilities and test equipment used in verifying the Calorimeter components and system modules shall be capable of producing and maintaining the test conditions with the installed test specimen (operating or non-operating, as appropriate). In any major test, facility performance shall be verified prior to the test either by review of its performance during a test that occurred a short time earlier or by conducting a test with a substitute test item.

4.2 Contamination Control Requirements

Contamination control of flight and test hardware during the verification program shall be in accordance with the requirements of the Calorimeter, Tracker, and Data Acquisition Contamination Control Plan [LAT-MD-00228]. Specific requirements for particulate or molecular contamination control shall be included in component/subsystem specifications and test plans and procedures.

4.3 Waivers and Exceptions

A waiver of or exception to the requirements of this specification shall be granted only by direction or concurrence of the Calorimeter Project Manager or his authorized representative through the Configuration Management process.

4.4 Failure and Retest Requirements

When a failure (non-conformance or trend indicating that an out-of-spec condition will result) occurs, determination shall be made as to the feasibility and value of continuing the test to completion. If corrective action is taken, the test shall be repeated to the extent necessary to demonstrate that the test item's reliability and verify satisfactory performance.

If during a test sequence a test item is operated in excess of design parameters and becomes unsuitable for further testing, a spare may be substituted. However, if the substitution affects the significance of test results, the test during which the item was replaced and any previously completed tests that are affected shall be repeated to the extent necessary to demonstrate satisfactory performance.

Failures shall be recorded and tracked as a problem record through the Calorimeter Work Order Authorization database. A WOA shall be completed for each test procedure conducted on the Calorimeter Modules and subsequent problem records may be tracked to a given WOA. If a problem record is entered for a given anomaly, corrective action steps may be dispositioned to close out the problem record. WOAs shall not be closed out unless all problem records are dispositioned.

4.5 Test Readiness Review (TRR)

All Calorimeter module tests shall be preceded by a test readiness review wherein the readiness of the test article, facilities, test equipment, and procedures are verified. For minor tests (i.e. component tests), reviews may be conducted by the key test personnel as outlined by the given test procedure or directive. For major tests (i.e. CAL module tests), formal reviews shall be conducted and chaired by the Calorimeter Project Manager or his designated representative.

4.6 Pre-Ship Review (PSR)

Following the tests of each Calorimeter Module, a formal review shall be held wherein test data are reviewed to determine conformance with the test requirements prior to delivering any flight level deliverables. Test summaries are required for all subsystem and system level qualification and flight level test programs. (Formal test reports may follow at a later date.)

Topics to be addressed at the review are as follows:

- Unit Revision Status
- Tests Performed and Summary Report
- Performance Review Summary
- Quality Review Summary
- Test Data Summary
- Problem / Failure Reports and Status
- Issues and Concerns
- Recommendations

The unit may be released for use after a successful PSR with all open items closed. However, a unit may be released for use with open issues as long as there is a plan for closure and the open issues do not affect the higher-level integration.

The PSR panel shall be comprised of representatives from Program Management, Systems Engineering, Performance Assurance, Subsystem Engineering, and other members of the collaboration as required. The panel will approve the release of the hardware for use on the LAT.

4.7 Test Sequence

In general, no specific test sequence is required, but the test program shall be arranged in a way to best disclose problems and failures associated with the characteristics of the hardware and the system requirements. The test sequence must satisfy the required verification tests for the given Calorimeter module. (Reference Table 2 Test Requirements Verification Matrix).

A detailed test sequence flow for the various Calorimeter Models are shown in Section 5.2.

4.8 Documentation Requirements

The following procedures and reports are required to conduct the verification program and document the results.

4.8.1 Test Procedure and Supporting Analysis

All prototype and flight hardware shall be verified and tested using procedures approved by the Calorimeter Project. Test procedures shall be prepared to describe the activities required by this verification specification.

For each test activity, the procedure shall include the configuration of the test article, objectives, facilities, instrumentation, safety considerations, contamination control, test phases and profiles, functional operations and inspections, test software descriptions, personnel responsibilities.

Procedures shall also contain details such as test descriptions and purposes; identification of the test article; specific test equipment (including calibration information if applicable) and fixtures; facility control sequences; test parameters, levels and tolerances; identification of hazards and hazardous operations; contamination control provisions; data sheets; step-by-step (chronological) procedures; pass/fail criteria and/or expected results; and data collection and processing requirements.

All supporting analysis shall be referenced in the test procedure and a copy shall be available during the test.

A Work Order Authorization (WOA) shall be completed referencing the name and LAT # of the procedure to be executed. This WOA form shall accompany the procedure at all times and serves as a means to track discrepancies that may be encountered while running the procedure. Quality control signoff points shall be addressed in the associated WOA.

Real-time modifications to the test procedures, shall be captured as required.

4.8.2 Test Report

Test reports shall be prepared after the completion of test activities for the Calorimeter modules. For each test activity, the report shall contain, as a minimum, the following:

- Description of test
- Criteria for pass/fail (or expected results)
- Deviations that were taken from the approved test plan/procedures
- Test results
- Test data

5 TESTING

5.1 Summary of Required Tests and Demonstrations

The following tests, demonstrations, and supplemental analyses are required for Calorimeter Modules. Where items are indicated on a selective basis, the verification test matrix (Table 2 of this document) shows applicability.

- Performance Tests (CPT, LPT); (selective basis)
- Pressure Profile Verification Analysis
- Static Load Test; (selective basis)
- Mass Properties; (measurement)
- Minimum Modal Frequency Verification Test; (Low Level Random Vibration)
- Sine Burst Vibration Strength Test
- Sine Vibration Test
- Random Vibration Test
- Interface Verification Test
- EMC/EMI Tests; (selective basis)
- Thermal Vacuum Test
- Thermal Balance Test; (selective basis)
- Bakeout

The above tests and demonstrations, and appropriate analyses and inspections, shall be conducted to provide assurance that the Calorimeter components and subsystem modules meet specified performance, functional, environmental, science, and design requirements.

5.2 Calorimeter Test Sequence

The Calorimeter shall be comprised of sixteen modules (Reference Figure 1, Section 2). These modules are considered flight models and shall be delivered and integrated to the LAT instrument. However, prior to production of the flight modules, three other modules shall be built and tested. These are the Engineering, the Structural, and Qualification CAL Module Models and shall be addressed in the following sections.

5.2.1 Engineering Model CAL Module

One Engineering Model (EM) CAL Module shall be built and tested at the qualification level. Subsequent CAL Models shall leverage manufacturing techniques and performance requirements from the engineering model. The EM Model shall be as close a representation of the Flight CAL modules as possible. The differences from the flight model are as follows:

- Dual PIN photodiodes shall be modified for flight.
- Optical epoxy used to bond PIN photodiodes to Crystals likely to change.
- EM CDE's manufactured in the USA.
- Carbon Composite Structure will use an improved curing process for flight.
- Base Plate interface to the Grid incorporates a shear pin joint design for flight

The flow of the Engineering Model CAL Module is shown in Figure 2 below:

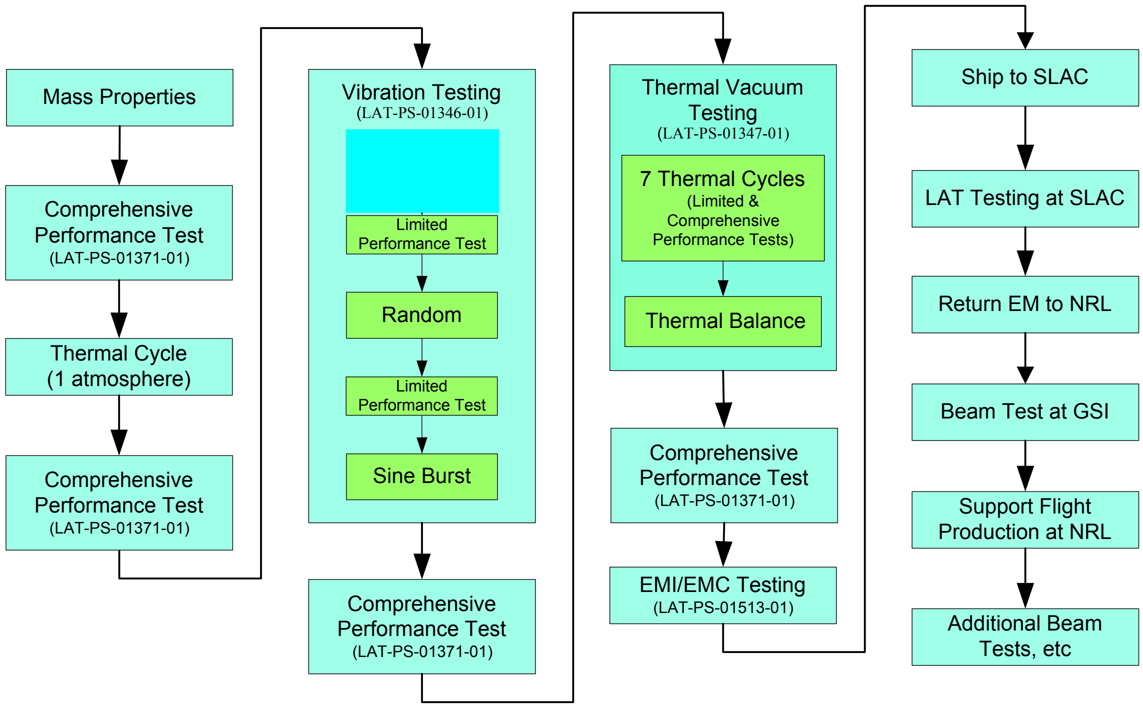

Figure 2: CAL Engineering Module Test Flow

5.2.2 Structural Model CAL Module

The Structural Model (SM) CAL module shall be built and tested at the qualification level. The composite structure is being fabricated by a French vendor and this model shall verify their production processes are satisfactory and repeatable.

5.2.3 Structural Flight Model CAL Module

One Structural Flight Model (SFM) CAL module shall be built and tested at the qualification level. The reason for a structural flight model is to verify process control and manufacturability has not changed. The structural flight model shall be produced using an autoclave. Once this model is tested and proven reliable, subsequent structures shall be mass produced.

The flow of the Structural / Flight Structural Model CAL Module is shown in Figure 3 below:

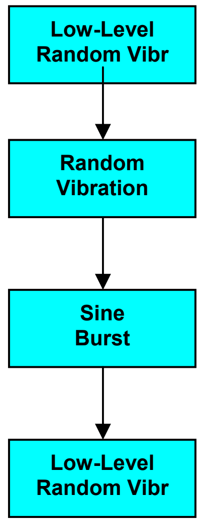

Figure 3: CAL Structural / Structural Flight Module Test Flow

5.2.4 Qualification Model CAL Module

One Qualification Model (QM) CAL Module shall be built and tested at the qualification level. Subsequent Flight CAL Models shall leverage manufacturing techniques and performance requirements from the qualification model. The qualification model shall be identical in components and manufacturing processes to the flight units.

The flow of the Qualification Model CAL Module is shown in Figure 4 below:

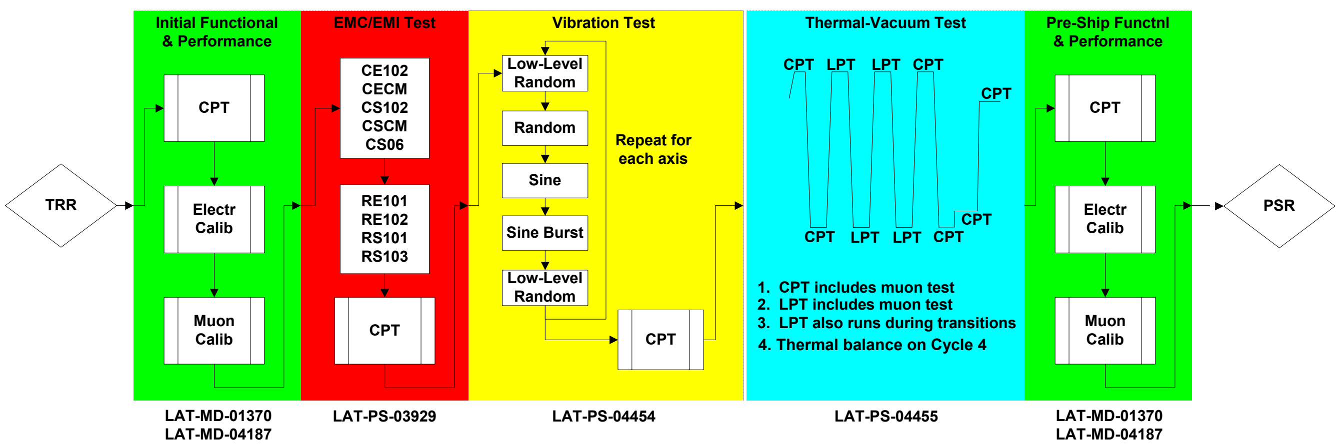

Figure 4: CAL Qualification Module Test Flow

5.2.5 Flight Model CAL Module

Seventeen Flight Model (FM) CAL Modules shall be built and tested at the acceptance level or deemed qualified by similarity. Sixteen of these modules, after passing the environmental test phase shall be delivered to the LAT instrument for integration. One module shall be reserved as a flight spare in the event a module shall become unusable.

The flow of the Flight Model CAL Module is shown in Figure 5.

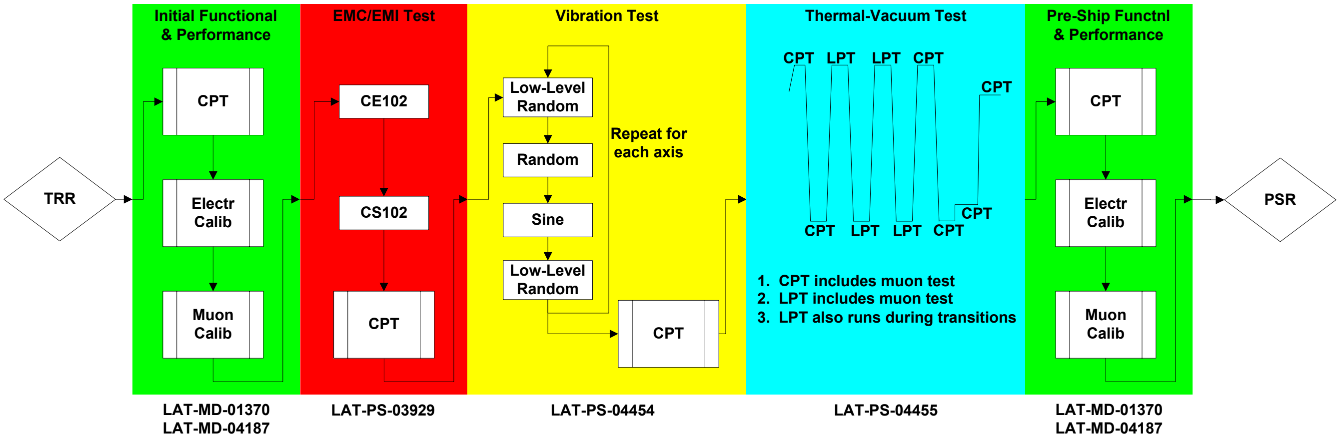

Figure 5: CAL Flight Module Test Flow

5.3 Science Verification and Calibration Tests

5.3.1 Comprehensive Performance Tests (CPT)

Comprehensive performance tests (CPT) shall be executed prior to and after each environmental test of each CAL Module. Data taken from each test is then compared to see if any changes to the test article have occurred as a result of the environmental test. During Thermal Vacuum testing, CPTs shall be run under vacuum at ambient, and High/Low temperatures during first and last thermal cycles. The operating performance of the CAL Module shall be verified over environmental ranges as well as specific CAL operational ranges.

5.3.2 Limited Performance Tests (LPT)

A Functional test of the CAL Modules shall be performed after the interface verification test to ensure the unit powers up correctly, and all circuit connections are in proper working order. This test shall be completed before each environmental test and during temperature dwells and transitions throughout thermal vacuum testing to check for intermittent failures.

5.3.3 Electronic Calibration Suite (ECS)

An Electronic Calibration Suite of each CAL Module shall be executed prior to the environmental test program and immediately prior to the Pre-Ship Review. Results of the PSR-ECS shall be delivered with the CAL as part of the reference calibration.

5.3.4 Muon Calibration (MuC)

A Muon Calibration (MuC) of each CAL Module shall be executed prior to the environmental test program and immediately prior to the Pre-Ship Review. (It may be possible to run a MuC at other times in the test sequence!) Results of the PSR-MuC shall be delivered with the CAL as part of the reference calibration.

5.4 Mechanical Tests

The following sections shall address the various mechanical verification methods (environmental tests, measurements, analysis, or inspection) that CAL Modules may be subject to.

5.4.1 Pressure Profile Verification Analysis

LAT components and assemblies shall be capable of withstanding the time rate of change of pressure in the launch vehicle fairing, as shown in LAT-SS-00778. In accordance with GEVS section 2.4.6, qualification by analysis must demonstrate a positive margin with respect to the maximum profile shown of 100%. Acceptance verification is not required.

5.4.2 Mass Properties

Measurement of the weight and calculated center of gravity of each CAL module shall be made to show compliance with the Requirements Verification Matrix (Table 2, Req't #5.3.3, Calorimeter Mass) and provide accurate data for the LAT mass properties control program.

5.4.3 Vibration Testing

5.4.3.1 Minimum Modal Frequency Verification Test

CAL modules shall be subjected to a low level random vibration test to verify its minimum modal frequency in each of three mutually perpendicular axes, one of which is normal to the mounting surface. This test shall be performed during the same test setup as that required for the random vibration test of section 5.4.4.3.

5.4.3.2 Random Vibration Test

CAL modules shall be subjected to a random vibration test in each of three mutually perpendicular axes in accordance with LAT-SS-00778.

5.4.3.3 Sine-Sweep Test

CAL modules shall be subjected to a sine-sweep test in each of three mutually perpendicular axes in accordance with LAT-SS-00778.

5.4.3.4 Sine-Burst Vibration Strength Test

Strength Verification of CAL Modules shall be demonstrated by subjecting the test article to quasi-static accelerations at the center-of-mass in accordance with LAT-SS-00778.

This shall be performed on CAL components and subsystem modules by using a low-frequency sine-burst technique.

5.5 Electrical Tests

The following sections shall address the various electrical verification methods (environmental tests, measurements, analysis, or inspection) that CAL Modules may be subject to.

5.5.1 Interface Verification

Interface verification tests (safe-to-mate) are performed prior to integration to flight hardware. The test serves to verify the integrity of the electrical interfaces (EGSE and Flight) and prevent damage to flight hardware as a result of equipment move, and mating/demating of connectors. The flowing tests may be performed as part of interface verification:

- Isolation
- Continuity
- Grounding
- Insulation Resistance (Hi-Pot)
- Power Distribution
- Command Distribution
- Signal Distribution

The CAL safe-to-mate procedure is LAT-PS-03933.

5.5.2 EMC/EMI

The general requirements for electromagnetic compatibility are as follows:

a) The Calorimeter Module electronics shall not generate electromagnetic interference that could adversely affect its own subsystems and components, other spacecraft level payloads, or the safety and operation of the launch vehicle (Delta II) and launch site.

b) The Calorimeter Module electronics shall not be susceptible to emissions that could adversely affect their safety and performance. This applies whether the emissions are self generated or emanate from other sources.

The CAL Module electronics shall be designed to function properly while operating in an electromagnetic field environment as defined by the following Emission and Susceptibility requirements as show in Table 7 below. The tests are performed to fixed levels which are intended to envelope those that may be expected during a typical mission and allow for some degradation of the hardware during the mission. The levels should be tailored to meet mission specific requirements, such as, the enveloping of launch vehicle and launch site environments.

Radiated Emissions and Susceptibility testing will be performed on each component at the levels as stated in the GLAST Electronmagnetic Interference (EMI) Requirements Document; [433-RQMT-0005], MIL-STD-461E; Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment (20 August 1999) and those taken from the GEVS-SE; General Environmental Verification Specification For STS & ELV Payloads, Subsystems, and Components.

5.5.3 ESD Compatibility

ESD compatibility tests will be conducted on each subsystem electrical component at the qualification level. These tests are to ensure proper grounding of the electrical/electronics assemblies with the LAT structure.

The CAL Module Grounding and Shielding Plan [LAT-SS-00272] shall address specific bonding resistance levels and level of shielding required to ensure the CAL modules are immune to the hazards of electro-static discharge potentials.

5.6 Thermal Tests

5.6.1 Thermal Vacuum

The CAL EM and QM Modules shall be subjected to a thermal vacuum test with thermal cycling to the qualification specified in LAT-SS-00778. The CAL FM Modules shall also undergo 4 (four) thermal vacuum cycles at the acceptance levels specified in LAT-SS-00778. At the hot and cold plateaus, a 4-hour, minimum soak at these temperatures will be demonstrated. Additional tests during the TVAC test are outlined below:

- Turn on shall be performed at each hot and cold temperature extremes for the QM and at the temperature extremes of the initial thermal cycle for the FM.
- CPT and muon collection shall be performed at the temperature extremes of the initial and last thermal cycle.
- LPT and muon collection shall be conducted at the temperature extremes of the intermediate thermal cycles and during thermal transitions, where system failures or intermittent problems are most likely to occur.

5.6.2 Thermal Cycle

Thermal cycling of CDEs and AFEE boards shall be conducted at ambient pressure and temperatures specified in the following documents:

- EM and QM CDEs in accordance with LAT-SS-02236
- FM CDEs in accordance with LAT-SS-02235

- EM, QM, and FM AFEE Boards in accordance with LAT-SS-01498

5.6.3 Thermal and Humidity

During the test phase of CAL component or subsystem, temperature and humidity measurements shall be recorded as part of the particular test procedure. A temperature and humidity data logger accompanies each CAL module throughout its movement within the test facility. Furthermore, temperature and humidity is recorded in the clean rooms used for assembly and test as well as electronic assembly. When not in test, components, subsystem shall be stored in a controlled environment as to maintain proper temperature and humidity levels. Temperature and humidity measurements from the data logs shall be incorporated in the qualification data package.

5.6.4 Bakeout

During the first hot cycle, a bakeout of the CAL Module shall be performed at a temperature in excess of 40C. Data from a residual gas analyzer (RGA) and thermoelectric quartz crystal microbalance (TQCM) shall be monitored to verify the effectiveness of bakeout.

Calorimeter Vacuum Bakeout Requirements including test cables may be found in Section 9.0 of the GLAST LAT Contamination Control Plan [LAT-MD-00228].

The thermal-vacuum test fulfills the bakeout function as the first “hot” soak can function as the bakeout level.