GAMMA-RAY LARGE AREA SPACE TELESCOPE (GLAST) PROJECT

SYSTEMS VERIFICATION PLAN

September 20, 2004

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

GAMMA-RAY LARGE AREA SPACE TELESCOPE
(GLAST)
PROJECT

GLAST SYSTEMS VERIFICATION PLAN

September 20, 2004

NASA Goddard Space Flight Center
Greenbelt, Maryland

GLAST Systems Verification Plan

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Acronyms

AR	Acceptance Review
BGO	Bismuth Germanate
CCB	Configuration Control Board
CCSDS	Consultative Committee for Space Data Systems
CDRL	Contract Data Requirements List
CLTU	Command Link Transmission Unit
CM	Configuration Management
DOORS	Dynamic Object Oriented Requirements System
DR	Discrepancy Report
DRB	Discrepancy Review Board
ETE	End-to-End
FOT	Flight Operations Team
FRR	Flight Readiness Review
FS	Flight Segment
GBM	GLAST Burst Monitor
GI	Guest Investigator
GLAST	Gamma ray Large Area Space Telescope
GN	Ground Network
GNC	Guidance Navigation and Control
GPO	GLAST Project Office
GPS	Global Positioning System
GS	Ground Segment
GSFC	Goddard Space Flight Center
GSSC	GLAST Science Support Center
HEASARC	High Energy Astrophysics Science Archive Research Center
I/F	Interface
ICD	Interface Control Document
IOC	Instrument Operations Center
IRD	Interface Requirements Document
ISOC	Instrument Science Operations Center
ITOS	Integrated Test and Operations System
ITWG	Integration and Test Working Group
LAT	Large Area Telescope
LCCB	Local Configuration Control Board
LV	Launch Vehicle
MOC	Mission Operations Center
MSFC	Marshall Space Flight Center
MSS	Mission System Specification
MTS	MOC Training Simulator
NASA	National Aeronautics and Space Administration
NLS	NASA Launch Services
ORE	Operational Readiness Exercises
ORR	Operational Readiness Review

ORT	Operational Readiness Tests
OSSMA	Office of Systems Safety and Mission Assurance
PSS	Portable Spacecraft Simulator
RSDO	Rapid Spacecraft Development Office
SC	Spacecraft
SGS	Space-Ground Segment
SLAC	Stanford Linear Accelerator Center
SN	Space Network
SPT	System Performance Test
SRD	Science Requirements Document
SVP	Systems Verification Plan
TDRSS	Tracking and Data Relay Satellite System
TRR	Test Readiness Reviews
USN	Universal Space Network
VCDU	Virtual Channel Data Unit
VWG	Verification Working Group

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The Gamma Ray Large Area Space Telescope (GLAST) Systems Verification Plan (SVP) documents the methodology the GLAST Project Office will use to verify system functionality and compliance with mission requirements during development, integration, and on-orbit checkout of the GLAST mission. The culmination of the verification concept presented in this plan is a mission readiness determination supporting the on-orbit handover (referred to as "operations handover") of the GLAST Observatory for full-time science operations.

Verification of the GLAST end to end mission system is the responsibility of the GLAST Project Office and is led by System Engineering. See section 3.6 for discussion of verification roles and responsibilities.

The SVP defines the overall philosophy for the GLAST system verification, including development, pre-launch integration testing and on-orbit checkout. Data and results gathered during execution of this verification effort are used to determine compliance with GLAST mission requirements, archived, and will be available for comparisons throughout the mission.

1.2 PROJECT OVERVIEW

The GLAST Project bridges the fields of astronomy and particle physics in the study of black hole particle jets and other high-energy phenomena using its two main instruments, the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM).

GLAST is an international collaboration of government agencies and academic institutions from the United States, France, Germany, Japan, Italy, and Sweden. The LAT is a joint project with NASA and the U.S. Department of Energy. The LAT will be constructed by Stanford University, the Stanford Linear Accelerator Center, the University of California, Santa Cruz, the Naval Research Laboratory, NASA Goddard Space Flight Center, and the international partners.

NASA Marshall Space Flight Center, along with the University of Alabama Huntsville and Germany will build the GBM. The overall mission management resides at NASA Goddard.

Spectrum Astro, Inc. is the spacecraft bus manufacturer and the observatory integrator. The spacecraft bus is based on the Spectrum Astro 200HP Rapid Spacecraft Development Office (RSDO) catalog bus.

The Mission Operations Center is located at GSFC and is a joint development between GSFC and Goldbelt-Orca. The data processing elements of the ground system are being developed by GSFC and the instrument teams jointly as well.

GLAST is a high-energy gamma-ray observatory designed for making observations of celestial sources in the energy band extending from 20 MeV to 300 GeV with complementary coverage between 10 keV and 25 MeV for gamma-ray bursts. This mission will:

1) Identify and study nature's high-energy particle accelerators through observations of active galactic nuclei, pulsars, stellar-mass black holes, supernova remnants, gamma-ray bursts, Solar and stellar flares, and the diffuse galactic and extragalactic high-energy radiation.
2) Use these sources to probe important physical parameters of the Galaxy and the Universe that are not readily measured with other observatories, such as the intensity of infrared radiation fields, magnetic fields strengths in cosmic particle accelerators, and diffuse gamma-ray fluxes from the Milky Way and nearby galaxies, and the diffuse extragalactic gamma-ray background radiation.
3) Use high-energy gamma rays to search for a variety of fundamentally new phenomena, such as particle dark matter, quantum gravity, and evaporating black holes.

The GLAST mission will start with a one-year survey of the gamma-ray sky, after which the observation program will be determined by proposals from the international science community. The mission is being designed for a lifetime of five years, with a goal of 10 years of operations.

For more information on the GLAST mission and science objectives please reference the GLAST website at http://glast.gsfc.nasa.gov/

1.3 SYSTEM SEGMENT OVERVIEW

The overall GLAST system is composed of three major segments as described below and shown in Figure 1-1. This architecture also provides the structure for the organization of mission verification.

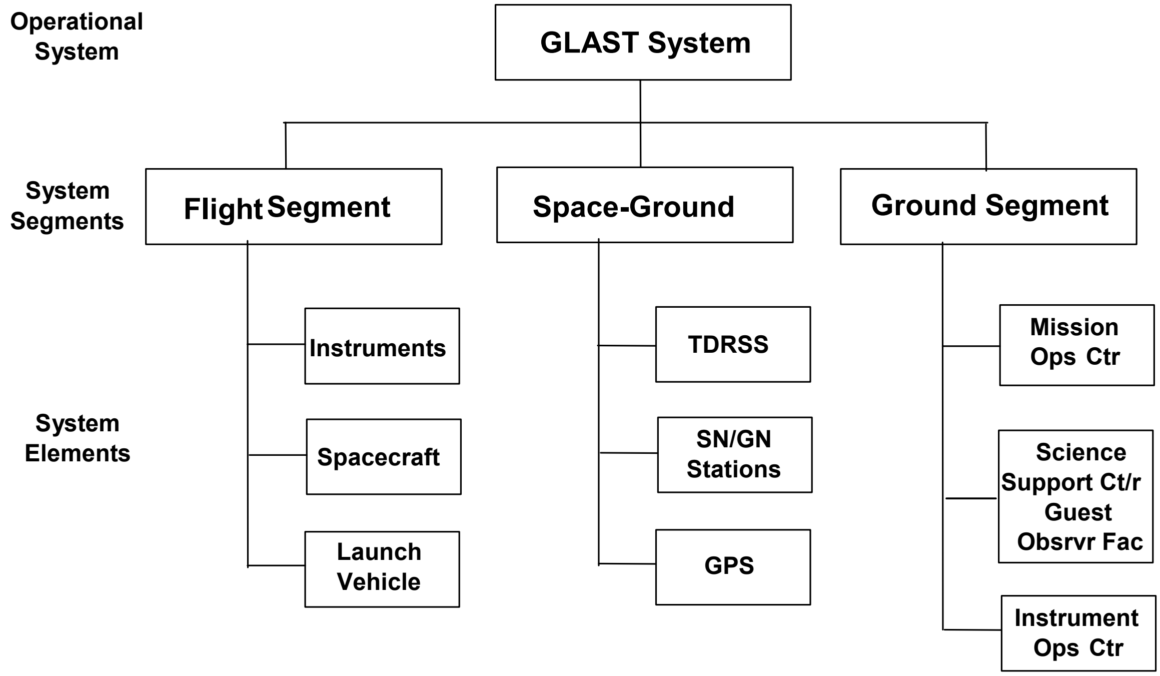


Figure 1-1 Architectural Block Diagram of the GLAST System

1.3.1 *Flight Segment*

The flight segment includes the launch vehicle and the observatory. The observatory is comprised of the spacecraft and the two instruments, the GBM and LAT.

1.3.1.1 Spacecraft

The spacecraft provides support for the instruments via a suite of subsystems and services. These include the structural bus on which the two science instruments are mounted, electrical power, thermal control, attitude determination and control, command and data handling, flight software, communication with the space network and ground stations, and, following the completion of the science mission, controlled re-entry via a propulsion system .

1.3.1.2 LAT

The Large Area Telescope (LAT) is a next-generation gamma-ray telescope that is the primary instrument for GLAST. It has a wide field-of-view and will detect gamma-rays in an energy range from 20 MeV to 300 GeV. Visible light has an energy of roughly 2 eV (electron volts). GLAST will detect gamma rays by using a concept known as pair production. An incident gamma ray interacts with a layer of dense material in the telescope (tungsten in the case of GLAST), producing an electron and positron pair. A positron is an anti-electron, having all the properties of an electron except it is positively charged. The original photon (gamma ray) no longer exists, its energy having gone to the two resulting particles. These electron-positron pairs are then tracked through the telescope using silicon strip detectors. By tracking the "pairs", the source location of the incident gamma ray can be determined. A device called a calorimeter is then used to measure the energy of the incident gamma ray via the energies of the electron-positron pairs.

One problem gamma-ray detectors have to contend with is that cosmic rays entering the telescope can trick the detector into thinking it has detected a gamma ray, when in fact it was an unwanted cosmic ray. To combat this problem, the LAT will be covered by an anti-coincidence detector, which is transparent to gamma rays, but will register a hit when most cosmic rays pass through it.

1.3.1.3 GBM

The secondary instrument onboard GLAST, the GLAST Burst Monitor (GBM), is composed of two sets of detectors – 12 sodium iodide (NaI) scintillators and two cylindrical bismuth germanate (BGO) scintillators – and will be used to aid in the study of gamma-ray bursts. The GBM extends the energy range of GLAST for observing bursts down to roughly 10 keV, providing the broadest continuous energy range coverage ever on a single spacecraft. Scintillation detectors absorb gamma rays and convert their energy into pulses of visible light. A photomultiplier tube converts each light pulse into an electrical pulse, whose amplitude indicates the energy of the original gamma ray. GBM cannot determine the arrival directions of individual gamma-ray photons, but can determine the direction to bursts of gamma rays, since different detectors view different areas of the sky. GBM will provide onboard triggers and approximate locations for bursts that the LAT cannot see. The spacecraft can then be re-pointed to observe any delayed high-energy emission from the burst.

1.3.1.4 Launch Vehicle

The Launch Vehicle element provides those assets and services associated with the launch vehicle and observatory-launch vehicle integration. Included along with the launch vehicle are all ground support equipment, property, and facilities to integrate the observatory and LV, verify their integration, and conduct pre-launch testing with the remainder of the system.

1.3.2 *Space-Ground Segment*

The space-ground segment consists of the systems that connect the flight and ground systems. These include the TDRSS and GPS spacecraft, the White Sands, USN ground stations, and the associated services and facilities.

1.3.3 *Ground Segment*

The ground segment is comprised of all of the operating centers and the communications networks that connect them. The Ground Segment includes all of the facilities needed to plan, schedule, execute, monitor, and maintain the health and safety of the observatory during the mission. The Ground Segment also provides those facilities and equipment needed to receive, archive, and distribute processed or raw science data products to the investigator/user facilities. These include the Mission Operations Center, GLAST Science Support Center (GSSC), the LAT Instrument Science Operations Center (LISOC), the GBM Instrument Operations Center (GIOC) and the High Energy Astrophysics Science Archive Research Center (HEASARC).

1.3.3.1 Mission Operations Center

The Mission Operations Center (MOC) will control the spacecraft by transmitting commands, and receiving the telemetry and science data. The MOC will perform Level 0 processing, which removes transmission artifacts from the telemetry and science data, and then will transmit them to the other organizations.

1.3.3.2 Instrument Operations Center

Each instrument team will maintain its own Instrument Operations Center (IOC) which will monitor the health of its instrument, take remedial action if necessary, perform the Level 1 processing, and support the instrument team's scientific studies. Level 1 data products are ready for astrophysical analyses; events are reconstructed, characterized as photon or non-photon, and described physically in terms of energy, arrival time and origin. The two IOCs will transmit the Level 1 data and other data products to the GSSC; the GSSC will have a backup capability for performing Level 1 processing. The GSSC and the IOCs will have joint responsibility for the definition of the relevant science analysis tools and for the representation of the instrument response functions; GSSC scientists will participate in the development of the science tools.

1.3.3.3 GLAST Science Support Center

The GSSC will be responsible for supporting the astronomical community's use of GLAST data by running the guest investigator (GI) program, providing analysis software and expertise, and disseminating GLAST data and results. The GSSC will be responsible for the science timeline. Finally, the GSSC will archive the mission's data.

1.4 SYSTEM DEFINITIONS

The definitions in Table 1-1 below will be used when defining the GLAST system.

Mission System	Definitions
Segments	Flight, Space-Ground Systems, Ground
Elements	Spacecraft, LAT, GBM, Launch Vehicle, Tracking and Data Relay Satellite System (TDRSS), Space Network (SN)/Ground Network (GN) Stations, Global Positioning System (GPS), MOC, GSSC, IOCs
Subsystems	Examples include: Structures and Mechanisms, Electrical Power, Guidance Navigation and Control (GN&C), Thermal Control, Propulsion, Communications, and Command and Data Handling (C&DH), Software, Tracker, Calorimeter, Anti-Coincidence Detector, Sodium Iodide Detectors, Bismuth Germinate Detectors

Table 1-1 System Definitions

2.0 APPLICABLE DOCUMENTS

The following documents are applicable to this plan.

433-Plan-0001, GLAST Project Plan

433-SRD-0001, GLAST Science Requirements Document

433-SPEC-0001, GLAST Mission System Specification

433-SPEC-0003, GLAST Spacecraft Performance Specification

433-RQMT-0006, Ground System Requirements Document

492-MOC-0002, MOC Functional and Performance Requirements Document

433-RQMT-0002, GSSC Functional Requirements Document

433-IRD-0001, GLAST LAT-SC Interface Requirements Document

433-IRD-0002, GLAST GBM-SC Interface Requirements Document

433-MAR-0001, GLAST LAT Mission Assurance Requirements

433-MAR-0002, GLAST GBM Mission Assurance Requirements

433-MAR-0003, GLAST Spacecraft Mission Assurance Requirements

433-MAR-0004, GLAST Ground Data System Mission Assurance Requirements

1196 ET-E46773-000, Observatory Performance Verification Plan

LAT-MD-408.1, LAT Program Instrument Performance Verification Plan

LAT-MD-446.5, LAT Science Verification Analysis and Calibration Plan

LAT-TD-02084, LAT Requirements Tracking Report

GBM-PLAN-1014, GBM Verification and Test Plan

433-ICD-0001, LAT-GBM Interface Control Document

1196 EI-Y46311-000, LAT-SC Interface Control Document

1196 EI-Y46312-000, GBM-SC Interface Control Document

1196 EO-R46502-000, Observatory Detailed Requirements, Traceability and Verification (CDRL 29)

3.0 VERIFICATION PROCESS

3.1 VERIFICATION APPROACH

GLAST verification activities are conducted across all development and integration phases of the GLAST system. The objective of the verification effort is to determine the extent to which the system can reliably support end-to-end system functionality and operations and the extent to which the system complies with the GLAST mission system requirements. The detailed Program Schedule is kept under configuration management and the most recent version can be found on the GLAST web site http://glast.gsfc.nasa.gov/project/.

As shown in Figure 3-1, GLAST verification is accomplished through an integrated hierarchical approach comprised of a series of verification activities. During the pre-launch phase, verification progresses from component to element to segment to system. Individual system components are verified by the segment or element providers. Next, elements and segments are verified by their providers against requirements or contractual specifications as appropriate. Throughout these lower-level verification activities, the GLAST Project Office has insight into the verification records and reports. Pre-launch verification of the mission system is accomplished by evaluation of inter-segment and end-to-end testing results against mission system requirements, and completed with pre-launch verification of the mission as a whole. Verification continues into the post-launch phase and focuses on real-time GLAST system performance verification.

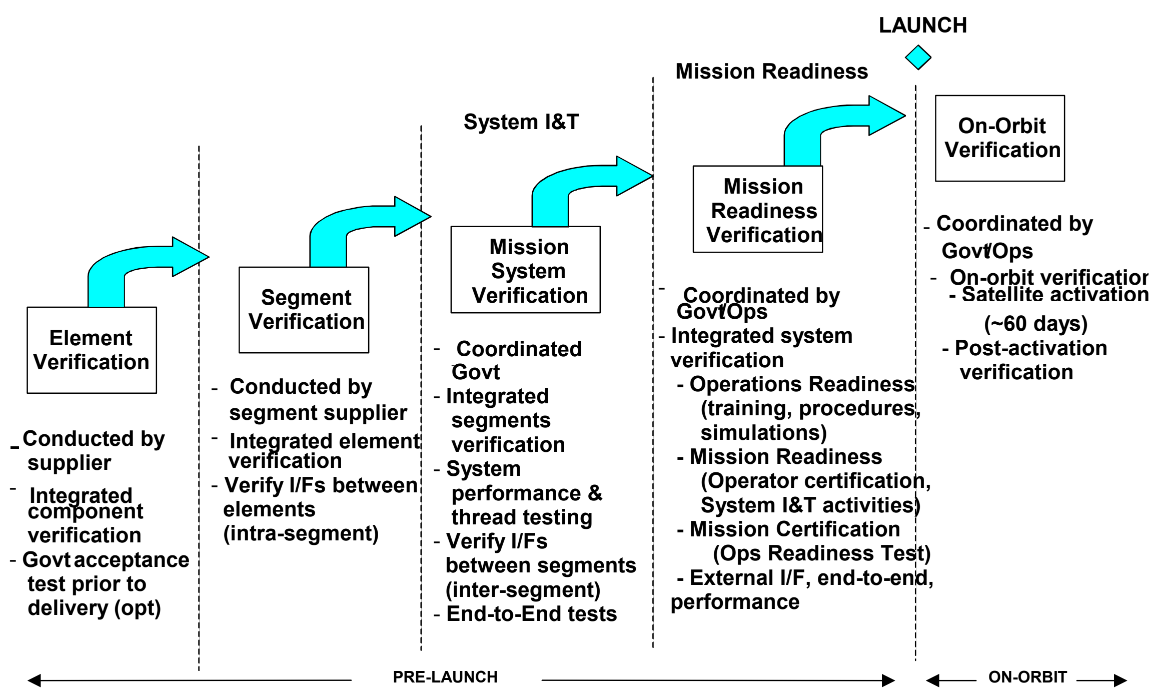


Figure 3-1 GLAST Verification Approach

3.2 VERIFICATION METHODS

The following processes are used to assess functionality and compliance with the requirements of the GLAST system and its segments:

Test –Measurement of performance to show compliance with specified requirement.

Analysis – Predicted performance using calculations to show compliance with specified performance.

Inspection – Visual proof of existence of specified characteristics or properties.

Demonstration – Observed compliance of functional operation or behavior with that specified.

3.3 VERIFICATION ACTIVITIES

The elements, segments, and systems comprising GLAST are verified utilizing the approach described in Section 3.1. Figure 3-2 shows the various GLAST verification activities, key input and output products, and organizations having lead responsibility for conducting the verification. This SVP only assigns verification responsibility to the providing organizations, which assign responsibility to subordinate organizations or contractors through appropriate requirements documents and statements of work. Further breakdown of specific responsibilities is detailed in the individual element verification plans. Results of each verification activity are documented in reports describing the verification processes performed, results, anomalies, and risks. Verification results and findings are incorporated into subsequent verification activities.

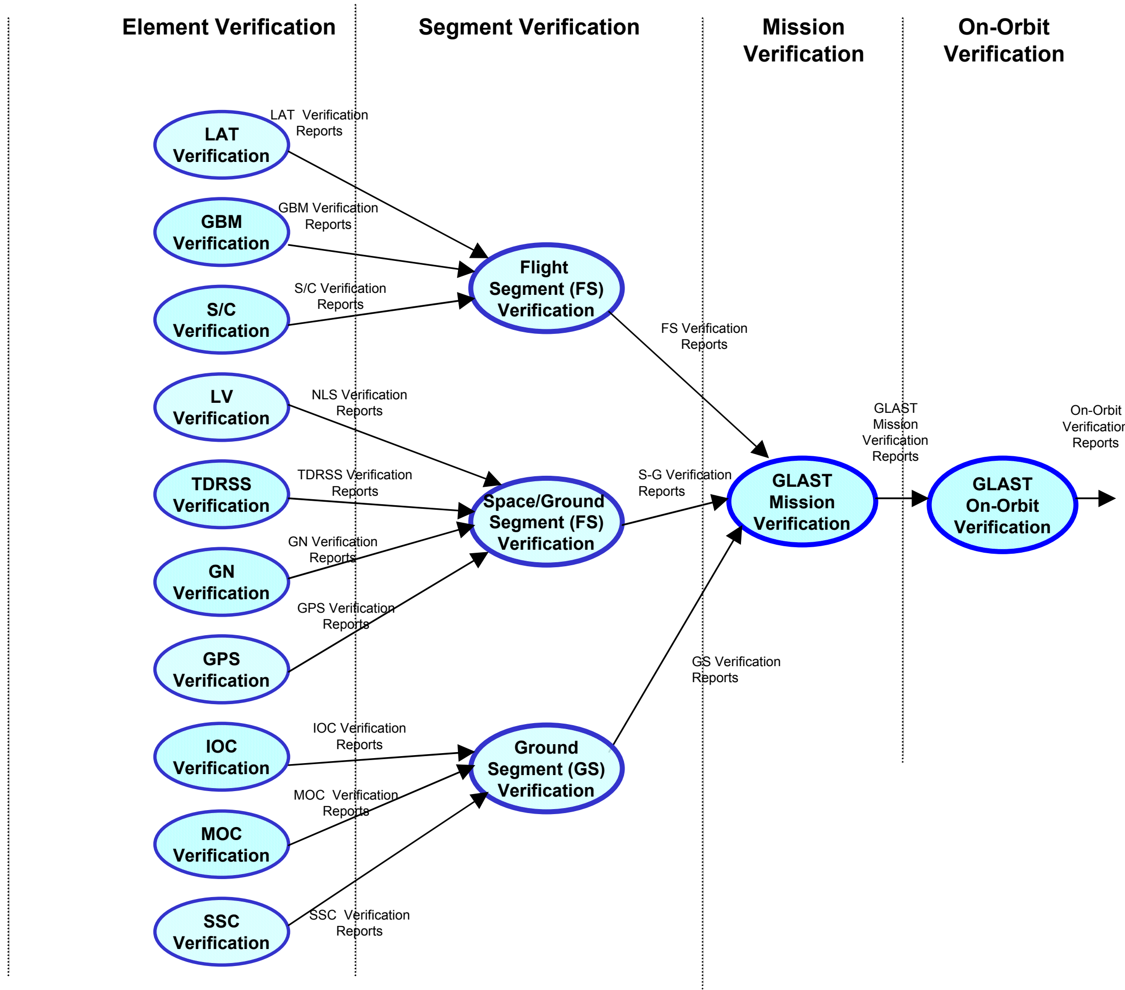


Figure 3-2 Verification Hierarchy

3.3.1 *Element Verification*

Element verification is performed prior to delivery of the element for integration. Element verification follows the integration of lower-level components that are verified as part of the developers' internal activities. Element verification focuses on requirements and/or contractor-provided specifications and is performed by the recipient government organization or their designated developer(s) as applicable. As an example, Flight Segment element verification activities for GLAST are shown in Table 3-1 below. Details of other elements are to be defined as segment definition proceeds.

Element	Verification Activities
Large Area Telescope (LAT) Instrument Element [SLAC]	Developer Performs: • Stand-alone LAT verification (analysis, testing, etc.) • Preliminary engineering tests to verify LAT interfaces with Spacecraft • Verifies against the LAT IPS, LAT-SC IRD, LAT-GBM ICD, and LAT-SC ICD
GLAST Burst Monitor (GBM) Instrument Element [MSFC]	Developer Performs: • Stand-alone GBM verification (analysis, testing, etc.) • Preliminary engineering tests to verify GBM interfaces with Spacecraft • Verifies against the GBM Requirements Database, GBM-SC IRD, LAT-GBM ICD, and GBM-SC ICD
Spacecraft (SC) Element [Spectrum Astro]	Developer Performs: • Stand-alone SC verification (analysis, testing, etc.) • Preliminary engineering tests to verify SC interfaces with science instruments • Engineering testing with Space-Ground Segment and Ground Segment elements • Verifies against CDRL 29, Spacecraft Detailed Requirements Document, LAT-SC ICD, GBM-SC ICD, the Spacecraft Performance Specification, LAT-SC IRD, and GBM-SC IRD

Table 3-1 Flight Segment Element Verification Activities

3.3.2 *Segment Verification*

Verified elements are integrated into segments and subsequent verification is performed at the segment level. Segment verification focuses on intra-segment interfaces defined by internal interface requirements and/or contractor-provided specifications and are performed by the organization(s) having lead responsibility for the segment verification. Specific segment verification activities for GLAST are shown in Table 3-2.

Segment	Verification Activities
Flight Segment (FS)	• Verify external interfaces of the Space segment • Integration and test of LAT, GBM, LV and associated interfaces with the spacecraft • Development testing with SGS • Development testing with GS
Space-Ground Segment (SGS)	• Stand-alone SGS verification (analysis, testing, etc.) • Development testing with GS • Development testing with FS
Ground Segment (GS)	• Stand-alone GS verification (analysis, testing, etc.) • Verification of mission management activities, satellite operations, and the space/ground communications • Verification of interfaces between GS elements • Development testing with FS • Development testing with SGS

Table 3-2 Segment Verification Activities

3.3.3 *Mission System Verification*

Pre-launch GLAST mission system verification is accomplished by integrating and testing the Flight, Space-Ground, and Ground Segments to ensure mission space-to-ground requirements are met and the system is ready for launch. Mission system verification is accomplished with Government coordination with participants from all necessary segments. Results from pre-launch mission system verification activities support launch readiness determinations at both the Flight Readiness Review (FRR) and Operations Readiness Review (ORR). This verification phase includes the following activities:

- ➢ Verify Space System and Ground System Interfaces
  - Telemetry processing between ground and space systems
  - Command processing between ground and space systems
  - Interconnecting network(s)

- ➢ Verification of end-to-end Space System/Ground System
  - End-to-end telemetry processing
  - End-to-end command processing
  - End-to-end mission data processing/distribution
  - Interconnecting network(s) for planning, management, etc.

3.3.4 *On-Orbit Verification*

GLAST on-orbit verification activities focus on verifying system functionality and performance. The sixty (60) day on-orbit verification is conducted in parallel with and following spacecraft and instrument activation and checkout. Verification activities during on-orbit operations are based upon the GLAST Level 1, SRD and MSS requirements. Detailed on-orbit verification activities are based on mission documents including the GLAST Project Mission Operations Concept Document, the GLAST On-Orbit Verification Plan, the LAT Calibration Plan and the GBM Calibration Plan. Results from on-orbit verification activities support the operations handover determination, after which responsibility for the Observatory and system operations are transferred from SAI to NASA. System integration and test is considered complete at operations handover in conjunction with the Acceptance Review (AR).

3.4 VERIFICATION REPORTING

The GLAST Level 2 requirements are documented in the Mission System Specification, the Science Requirements Document (SRD), and associated Interface Requirements documents. The traceability of requirements between these documents and lower level requirements documents are contained in a database implemented in the Dynamic Object Oriented Requirements System (DOORS). When requirements are verified through subsystem, element, segment and system level tests (or other method of verification) the results will be reviewed and status populated within the DOORS databases.

Requirements verification matrices (RVMs) are configuration managed within the documents containing the requirements in the matrix. The GLAST Project Office will maintain verification matrices for the SRD and MSS. The Level 1 Mission requirements are a subset of the SRD requirements, so the SRD RVM will serve as the RVM for Level 1 requirements. The RVMs for the observatory will be contained within CDRL 29 maintained by Spectrum Astro. For SRD and MSS observatory requirements that Spectrum Astro has been assigned as the owner of, the SRD and MSS RVMs will point to the appropriate section of CDRL 29. Spectrum Astro also maintains verification matrices in the ICDs for the LAT and GBM instruments (Large Area Telescope (LAT) to Spacecraft (SC) Interface Control Document 1196 EI-Y46311-000 and GLAST Burst Monitor (GBM) to Spacecraft (SC) Interface Control Document 1196 EI-Y46312-000).

The LAT maintains its verification matrices in LAT-TD-02084, LAT Requirements Tracking Report. The GBM maintains its verification matrices in GBM-PLAN-1014, GBM Verification and Test Plan.

During element or segment development, engineering development activities (e.g., informal engineering tests) will be of benefit in reducing risk in high-risk development areas such as segment interfaces. These interface tests are mutually agreed to by the development organizations. Where feasible, engineering activities provide an informal “test” opportunity to facilitate development and identify potential disconnects as early as possible. Engineering development activities involving segment interfaces are coordinated by the development organizations with assistance (when necessary) by the Government. Typically, these activities are performed during the development phase, on an as available basis, and are not tied to formal schedules or deliverables, however results of such activities will be recorded and communicated at an engineering level.

Formal verification activities such as the End-to-End tests are coordinated by the Integration and Test Working Group (see section 4.3.2). Formal test plans, test configuration, requirements to be verified, procedures, quality assurance, and test reporting are all documented and placed under configuration control. Results of the testing activity are used to assess the system's performance or functionality against the stated requirements for the tests.

3.5 DISCREPANCY REPORTING

During formal verification activities, the Segments will be responsible for documenting and capturing Discrepancy Reports (DR) related information in their local DR Tracking tool. DRs identified as effecting launch and early orbit operations, seriously affecting system performance, effecting inter-segment interfaces, or meet the criteria defined by the System Level Discrepancy Review Board (DRB), will be forwarded to the GPO to be ingested into the GPO System Level DR Tracking Tool. The GPO will collect and route DRs as appropriate to the to mission segment and element teams. DRs impacting test planning and test preparation activities (i.e., required by another subsystem, element or segment to generate additional products and/or messages) will be forwarded to the ITWG Team to provide for test re-planning and assess impacts to test schedule. As the DRs are evaluated, assigned and progress through their various states, the updated information will be provided to the ITWG, on approximately a weekly basis, to ensure that both databases are correct and in sync.

During the execution of the Mission End-to-End Tests (ETEs), a Local Configuration Control Board (LCCB) will be convened to review any discrepancy reports generated during the test. The board will be comprised of representatives from the GPO, the segment developers, quality assurance, and others as needed. The board will determine the validity of the reports as well as the appropriate segment/element to which the DR will be submitted.

Systems level and lower level DR processes will be managed so that they merge together to sustain higher levels of integration and on-orbit operations.

3.6 VERIFICATION ROLES AND RESPONSIBILITIES

3.6.1 *Developer Responsibilities*

Verification of individual components, subsystems, elements and segments is the responsibility of the developers and is governed by contractual requirements. Mission

Integration and Testing activities that support the verification of the various elements and segments are coordinated by the GPO and to the greatest extent possible, leverage testing activities that are planned by the implementing organizations. It is expected that each developer will participate in inter-segment test and verification activities based upon interface requirements that are either called out in their contract, or defined in the Interface Requirement Documents.

3.6.2 Mission Systems Engineering Responsibilities

GLAST Project Office Systems Engineering is responsible for the verification of the end-to-end GLAST mission system. The scope of the verification program runs from individual component manufacture through on-orbit transition of the system to operations. Project Office Systems Engineering is responsible for the integration of each of the mission element verification programs into verification of the overall mission. Systems is responsible for ensuring the completeness and integrity of the verification methods and plans. Appropriate categories of verification include test, analysis, inspection and demonstration. Verification by test is implemented through the integration and test program. Systems develops and maintains the verification matrices for Project level requirements and ensures that the mission element verification matrices support mission level verification. Project systems engineering maintains insight into the element verification programs and conducts reviews and audits to ensure their integrity. Project Office Systems Engineering chairs the Verification Working Group (VWG), which is described further in section 4.3.1.

3.6.3 *Mission Integration And Test Lead Responsibilities*

The Mission Integration and Test lead is responsible for the GLAST test program. The I&T lead will ensure that all requirements to be verified by test are appropriately verified through the Mission Test Program. The Mission I&T lead or designee will chair the Integration and Test Working Group. The working group is responsible for the planning, coordination, and execution of the mission End-to-End Tests. The Mission Integration and Test lead will work closely with the segment and element integration and tests teams to ensure a successful test program.

4.0 INTEGRATION AND TEST

4.1 INTEGRATION AND TEST ACTIVITIES

This section describes the integration and testing activities that support the verification of the GLAST Mission System. Integration and testing activities and associated test schedules will be coordinated between GPO and the developers.

The Mission-level test activities and milestones are under the direction of the GLAST Integration and Test Lead. As the program progresses through the implementation phase, concurrence for inter-related system-level testing activities will be coordinated by the

ITWG. Final authority for test execution and resolution of issues resides with GLAST Integration and Test lead or designee.

The design, development, and execution of the End-to-End tests (ETEs), which will be used to verify the mission system will be documented as part of the GLAST Ground System Test Plan. The ETEs will be designed as a build up of capabilities to test the end-to-end capabilities and interactions of the mission system and thus will follow an evolutionary approach that runs parallel to the flight and ground activities as they mature and become integrated. All GLAST Mission Level 2 requirements verified by test will be executed in at least one of the ETEs.

The GLAST System is integrated, validated and verified in incremental stages. This incremental testing aids in early verification and ensures the System meets its full complement of mission requirements. Testing of the systems at higher levels of integration will not be performed unless verification procedures have first been carried out at the lower levels of integration.

The following are the test phases planned and discussed in detail in subsequent sections:

- Development/Implementation Phase
- Mission System I&T Phase
- Mission Readiness Phase
- On-Orbit Checkout Phase

The test phases are divided into those performed by the developers (Development/Implementation Phase) and those performed by Mission I&T and operations contractors. During each test phase, tests are executed in order to verify the ability of the system to meet its requirements at the earliest time possible and in direct relationship to its maturity while seeking to reduce risk.

4.1.1 *Implementation/Development Phase*

During the Implementation/Development phase, tests are developed and performed by the appropriate developers. Examples of the test types performed during this phase are listed below. Specific test scenarios and objectives are captured within the appropriate lower level test plans.

- Element Development (functional) Tests
- Segment Development (functional and performance) Tests
- Interface Tests (as appropriate)

At the element level, development tests address the verification of requirements corresponding to an element and its level of maturity. Requirements such as interface requirements and design/implementation specifications drive these tests. Element development tests are developed and performed by the appropriate developers.

Segment tests provide the verification of each allocated deliverable segment requirement. Requirements such as interface requirements and segment specifications drive these tests. Segment tests are developed and performed by the appropriate segment developer. For additional details pertaining to segment level test and verification activities, refer to the individual segment test plans listed in the reference document list in Section 2 of this document.

Interface tests focus on interfaces between elements/segments and are primarily driven by interface requirement specifications, and interface design/implementation specifications. Although interface testing would be best served using the actual target systems, simulators may be a resource used during this phase. For interface tests that utilize simulators, simulators must be verified before tests are conducted. For interface tests that focus on the transfer of data both inter- and intra-segments, it should be noted that the focus is on the transfer and not on the data being transferred. (Data content and formats are verified by the development tests). It should also be noted that although simulators/emulators may be used in development, the final verification of an interface at the System level is to be made (to the furthest extent possible) with the operational segment or external at either end of the interface.

4.1.2 *Mission Systems I&T Phase*

During the Mission Systems I&T phase, tests are developed by and executed under the guidance of the GLAST Integration and Test Manager or designee. During this phase, the development/operations contractors participate as members of the I&T Working Group. Specifics of each test to be conducted during this phase will be documented in an individual test plan. The test plan is the responsibility of the Mission Systems I&T manager, and will be developed and coordinated as part of the I&T working group. A high level description for each system test is contained in the End-to-End section of the GLAST Ground System Test Plan.

The main purpose of the Mission Systems I&T phase is to exercise capabilities and/or functions that cross multiple segments. The Mission Systems I&T activities verify Mission requirements and will leverage to the fullest extent possible any verification activities conducted at lower levels. These system tests are primarily driven by Level 2 Mission Requirements. Systems level testing may utilize draft operational procedures to derive the actual test procedures where appropriate and represent to the fullest extent possible, typical mission operations. Specific test data are captured within the appropriate lower level test plans.

4.1.2.1 GLAST End-to-End Tests (ETEs)

ETEs are defined to exercise the flight and ground end-to-end functionality and interactions. Each ETE is comprised of functional thread and interface tests that provide a continuing higher degree of confidence leading up to operational readiness. The ETEs follow an evolutionary approach that runs in parallel to the flight and ground activities as they mature and become a fully integrated system. At the time of execution of each ETE, it is expected that all relevant interfaces have been successfully verified to the extent possible by the developers. An informal "dry run" is expected to be performed prior to each ETE in order to "shake out" test procedures and the test environment. These dry runs maybe accomplished through the use of simulators or informal interface tests. For tests involving the observatory, the hot bench simulator will be used to shake out the procedures. A Test Data Sheet will be generated for each ETE. The purpose of the Test Data Sheet is to provide a summary of the activities and resources associated with the particular test. It is intended that the Test Data Sheets be used as a basis for the development of lower level (detailed) test plans which would contain all of the information necessary to successfully conduct the test. Each ETE Test Plan will contain a timeline and the sequencing of planned activities. As the Sequence of Events matures it will be used to generate the Test Script, which will contain all activities and key strokes required throughout the test. The Test Script will be reviewed and approved by all participating segments.

4.1.3 *Mission Readiness Planning*

During the Mission Readiness Phase, tests are designed primarily to train the operations staff & management, to refine the operating procedures, and to exercise the System. These tests include Operations Exercises, Operations Readiness Tests, System Performance Tests, Launch Rehearsals, and Launch Site loop-back with the MOC. The tests ensure that the operational staff, procedures, and Systems perform as a single unit and are ready to support launch and mission operations. These tests focus on nominal as well as contingency operations.

The following set of Mission Readiness activities is preliminary. Further details will be provided by the Mission Readiness Manager and will be documented in the Mission Readiness Plan.

4.1.4 *Operations Readiness Exercises (OREs)*

These exercises are performed for training refinement of operational scenarios and procedures. The OREs lead up to an Operations Readiness Test. Details of these events will be captured in the Mission Readiness Plan.

4.1.5 *Operations Readiness Tests (ORTs)*

The objective of this test is to certify System hardware & software, operations, and procedures are ready to support the launch. Details of these tests will be captured in a Mission Readiness Plan.

4.1.6 *GLAST System Performance Tests (SPTs)*

These tests focus on performance of data throughput. The system is exercised through a series of normal operations to include real-time commanding, execution of stored commands, and routing of satellite data through the ground system. Although the SPTs are performed by the operations team and within the Mission Readiness phase, these tests remain under the purview of the I&T Working Group. These tests if possible will be run with the spacecraft in combination with other tests, or with the hot bench simulator.

4.1.7 *On-Orbit Phase*

On-orbit verification activities focus on verifying System functionality and performance. On-orbit verification is conducted in parallel with and following satellite and instrument activation and checkout. Verification activities during on-orbit operations are generally based upon the GLAST Mission System Specification and Operations Concept document. Detailed on-orbit verification activities are based on Government and developer mission concepts and operations documents and Government/developer calibration and validation plans. Results from on-orbit verification activities support the operations handover determination. System integration and test is considered complete at operations handover. However, calibration and validation of the System continues past operations handover.

4.2 TEST RESOURCES

4.2.1 *Test Systems and Tools*

A variety of test facilities and systems will be used for the integrated spacecraft and ground system tests.

4.2.1.1 MOC Training Simulator

The MOC Training Simulator (MTS) is a medium fidelity simulator that will be used to develop and verify operational procedures, train the Flight Operations Team (FOT), and conduct mission simulations. The MTS will consist of a commercial RAD750 CPU running a modified version of the GLAST flight software, a GNC dynamic simulator, and a control PC.

The MTS will reside in the MOC and will connect to the MOC networks via a TCP/IP connection. The MTS will provide the MOC Command and Telemetry system with real time telemetry in the form of CCSDS VCDUs. The MTS will receive command uplinks via the TCP/IP connection in CCSDS CLTUs.

The MTS will be capable of modeling the GLAST observatory performance via dynamic models and delivered or user defined scripts. The MTS will be capable of proctoring all telemetry points that are not simulated dynamically, including the GLAST instruments. The MTS will provide the capability to save the current configuration to a file and restart the simulator.

4.2.1.2 Hotbench

The Hotbench is a high fidelity simulator that includes engineering models (EMs) of the C&DH and EPS subsystems of the spacecraft. To simulate the LAT the Hotbench will incorporate the LAT ISIS (Instrument to Spacecraft Interface Simulator), which contains EM hardware for interfaces to the spacecraft and has simulated detectors. The LAT ISIS is single string. To simulate the GBM the Hotbench will incorporate an EM Data Processing Unit (DPU), simulated power supply, and simulators for all detectors. The Hotbench will provide scripts that will simulate EM hardware that is not connected to the Hotbench. The Hotbench will host an exact duplicate image of the Flight Software that is delivered to the Observatory. The Hotbench will issue commands and interpret telemetry using and Astro-RT workstation running the current GLAST Observatory flight database.

The Hotbench will reside at the Spectrum Astro facility. The MOC will have access to the Hotbench in order to validate operational procedures, perform Ground System testing, and perform anomaly resolution testing. ITOS workstations resident at the Spectrum Astro facility will provide local access to the Hotbench if necessary.

4.2.1.3 Portable Spacecraft Simulator

The PSS is a low fidelity, portable, command and telemetry simulator that is used for Ground System development and checkout. The PSS will provide support for all Housekeeping command and telemetry data rates. The PSS will also provide a 40Mbps science data stream in order to test Ground System elements that require the higher science data rates. The PSS will provide an interface to proctor all telemetry points in the Project Database.

The PSS will be capable of being shipped to the USN ground stations in order to facilitate interface testing with the GLAST Ground Stations. A software only version will reside in the MOC in order to provide a test tool for the FOT.

4.2.2 *Test Data Set Sources*

The following test data sources have been identified to support I&T activities:

- Instrument data provided by instrument providers
- Observatory data provided during thermal vacuum (by the spacecraft vendor) and other observatory tests

The ITWG will serve as the test data working group for all system level tests. Instrument data will be provided by the instrument providers and used to verify the ground data processing. As opportunities arise, observatory data will be captured (by the spacecraft vendor) and provided to the Ground System during the thermal vacuum test and other observatory tests. In addition, the Ground System will have the capability to listen passively during spacecraft and observatory testing.

4.3 WORKING GROUPS

4.3.1 *Verification Working Group*

The Verification Working Group (VWG) is operated under GLAST Project Systems Engineering. The VWG coordinates and communicates verification activities across mission element boundaries and through the verification phases of element integration and test, mission system integration and test, and on-orbit operations. These activities include determination of the adequacy of verification methods, review of test plans, attendance at test readiness review meetings, review of test results and resolution of test discrepancies. The VWG interfaces with the I&T and Mission Ops Working Groups to identify specifics of how, when and where requirements will be verified. The GLAST Project Mission Systems Engineer chairs the VWG. The Charter of the VWG is contained in Appendix A.

4.3.2 *Integration and Test Working Group*

The Integration and Test Working Group (ITWG) is responsible for the development and implementation of the integration and testing activities between segments at the System level. The ITWG works with each segment's integration and test team to understand each segment's test and verification process and schedule in order to develop and implement mission system integration and test program. At the System level of test and verification, the ITWG coordinates the test configurations, test schedules and test objectives. The GLAST Mission Integration and Test Manager or designee chairs the ITWG.

4.4 INTEGRATION AND TEST SUPPORT ACTIVITIES

4.4.1 *Configuration Management (CM)*

At the Mission System level of verification, all deliverable application software, application documentation, test documentation and software test tools, will be controlled via the GLAST Project Configuration Management and in accordance with the GLAST

Configuration Management Plan. This applies to artifacts and activities at the System level and is not intended to supersede the configuration management procedures of the development activities operating outside the scope of the GLAST CM program. Through the development phase, the developer's CM organization will provide the software library function.

4.4.2 *Risk Management*

At the Mission System level, the GLAST Project Risk Management process identifies risks and mitigation plans, executes mitigation plans, as well as updates and provides status to project management on all potential and identified risks.

This process includes continuous evaluation of potential risks through the formulation and implementation phases.

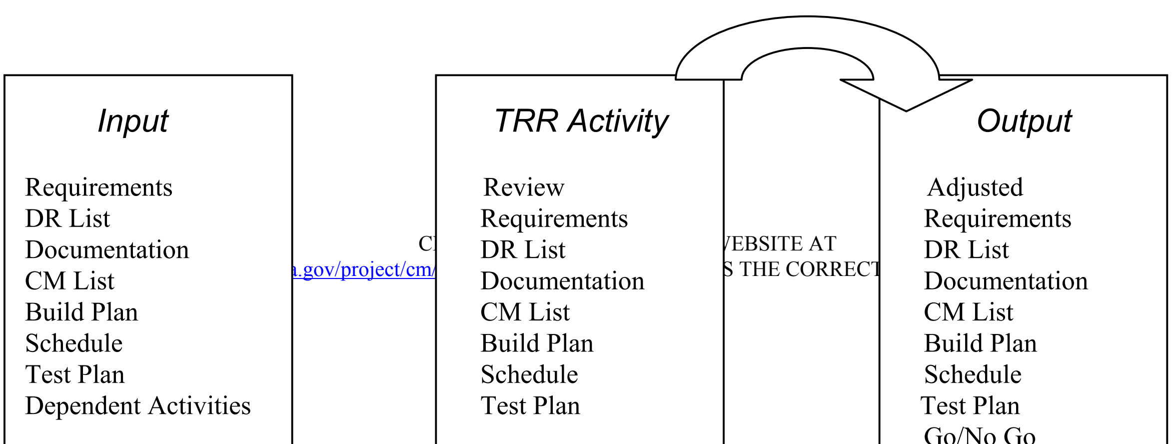
4.4.3 *Systems Safety and Mission Assurance*

The Office of Systems Safety and Mission Assurance (OSSMA) oversees the system integration and test processes to ensure program requirements and contractual requirements are achieved. The GLAST Systems Assurance Manager is responsible for coordinating Government support of these activities. This support is detailed in the GLAST MAR and the Surveillance Plans. The OSSMA initiates Government oversight and Government inspection through the OSSMA support contractor.

The observatory developer is responsible for ensuring appropriate inspections are implemented in the observatory integration and test flow as required per the satellite contract. The observatory developer is also responsible for documenting and supporting the investigation of anomalies that arise during integration and test of the observatory.

4.5 TEST READINESS REVIEWS

A Test Readiness Review (TRR) or its equivalent will be conducted prior to each major test evolution in order to ensure that for the system under test, support activities are prepared to conduct the test, that all prerequisites and/or dependencies identified in the test plan have been addressed and all known problems as well as their impact to the test activity are reviewed. The TRR serves as the formal turnover of the system under test from the development team to the test team. TRRs are to be negotiated with the developer and performed as depicted in Figure 4-1.



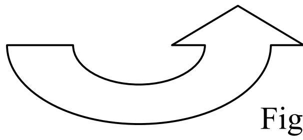
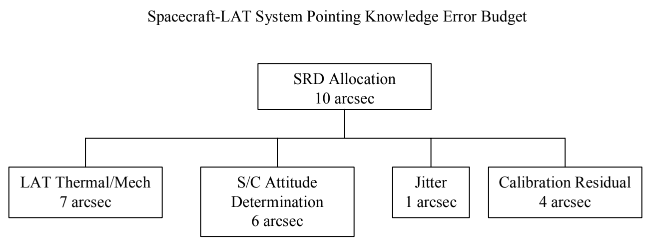


Figure 4-1 TRR Process

4.6 SYSTEM VERIFICATION PLANS

Table 4-1 below indicates mission requirements that will be verified by the GLAST Project Office. These are overarching requirements that cannot be verified by a single mission element or requirements that span multiple interfaces. These requirements are contained in the Science Requirements Document (SRD) and Mission Systems Spec (MSS). Both the SRD and MSS are Level 2 documents. The Level 1 mission requirements are a subset of the requirements contained in the SRD, so this list can be considered to have taken those requirements into account as well. When a parent-child relationship exists between these requirements in the SRD and MSS, they are grouped together in the table. The configuration-managed versions of the verification matrices for these requirements will reside in the SRD and MSS.

Requirement Doc	Requirement Number	Requirement
SRD	12	Source Location Determination < 0.5 arcmin High latitude source of 10^{-7} cm^{-2} s^{-1} flux at >100 MeV with a photon spectral index of -2.0 above a flat background and assuming no spectral cut-off. 1 sigma radius. 1-year survey. Derived quantities delimited by double-lined box. (*This requirements is derived from other science requirements in the SRD*)
SRD	36	Pointing Knowledge < 10 arcsec 1 sigma radius.
MSS	3.3.1.11 Pointing Knowledge Allocations	The contributions to the radius of the pointing knowledge error circle apportioned below shall support the determination of the direction of any observed gamma-ray event, regardless of the direction of the event.
MSS	3.3.1.11.1 LAT-SC	A pointing knowledge requirement of 10 arc seconds, 1 sigma, radial, for the LAT-SC system shall be met by the following end-

	System	to-end error budget over the life of the mission, see Figure 3-2. The end-to-end spacecraft-LAT system error considered here does not include the LAT point spread function (PSF).  Figure 3-2 Spacecraft-LAT Pointing Knowledge Error Budget
MSS	3.3.1.11.1.4 Calibration Residual	Residual errors in on-orbit LAT-spacecraft alignment calibration shall be less than 4 arc seconds, 1σ, radial.
MSS	3.1.2.1 Observation Plans	The GLAST system shall carry out the observation plans of GLAST investigators.
MSS	3.1.2.6 Validated Science Data	The GLAST system shall provide validated science data to the GLAST user community.
MSS	3.1.3.1 Fault Handling Capability	The GLAST system shall provide the capability for resolving flight hardware and software faults and anomalies.
SRD	34	GRB Notification Time to Ground by Spacecraft [6] < 7 sec 6 Time from spacecraft receipt of GRB notification from GBM or LAT to delivery to the Gamma-ray Coordinates Network (GCN) computer for 80% of all GRBs detected by the GBM or LAT.
MSS	3.1.4.1 Alert Response Time	The alert response time shall be less than 7 seconds with a goal of less than 4 seconds from the time of spacecraft receipt of GRB notification from GBM or LAT to delivery to the Gamma-ray Coordinates Network (GCN) computer for 80% of all GRBs detected by the GBM or LAT.
SRD	42	Observing Efficiency [11] > 90 % 11 Fraction of time with data return, not including SAA effects

MSS	3.1.4.2 Observing Efficiency	The GLAST system shall achieve an observing efficiency of at least 90 % with a goal of 95 %.
SRD	43	Data Loss [12] < 2 % 12 Fraction of data taken by the instruments but not delivered to the IOC. Not including SAA data loss. Not including instrument deadtime.
MSS	3.1.4.2.3 Data Loss	The total data loss of less than 2 % with a goal of less than 1 % in the data delivery part of the GLAST system shall be met with the following allocations: 3.1.4.2.3.1 The data loss allocated to spacecraft malfunctions that occur in the science data flow and that prevent delivery of acquired data (without incurring safe mode) shall not exceed 0.1% of mission science data. 3.1.4.2.3.2 The total data loss in the data delivery part of the GLAST system, excluding Spacecraft Data Loss, shall be less than 1.9% with a goal of less than 0.9%
SRD	44	Data Corruption [13] $< 10^{-10}$ 13 Fraction of undetected corrupted events.

Table 4-1 Mission System Requirements

APPENDIX A. VERIFICATION WORKING GROUP (VWG) CHARTER

GLAST Verification Working Group

Charter

Coordinate timely verification of GLAST mission across all elements including end-to-end performance.

Key Functions

Coordinate and communicate verification activities across mission element boundaries. These activities include determination of the adequacy of verification methods, review of test plans, attendance at test readiness review meetings, review of test results and resolution of test discrepancies. Assure useful and timely cross-element input into verification processes.

Scope

The Verification Working Group is concerned with the end-to-end verification of the mission, mission elements, and their subsystems. Interaction with verification activities below the element subsystem level is to be considered on a case-by-case basis.

Chair

GLAST Mission Systems Engineer

Membership

Representatives from GLAST Project Office, Spectrum Astro, SLAC/LAT, MSFC/GBM, KSC, and Ground System contractors.

Responsibilities

Provide a mission-wide forum for the communication of verification issues.
Interface with the I&T and Mission Ops Working Groups to identify specifics of how, when and where requirements will be verified.
Identify verification issues for the attention of the ISET and the integrated continuous risk management process.

Tasks

Track status and assess priority of verification issues for communication to ISET and continuous risk management process.

Maintain and track the end-to-end mission verification plan

Identify and track mission requirements documents, performance specifications, interfaces, and databases that need to be verified.

Support the development of verification matrices across all mission elements and end-to-end mission.

Support the development of the comprehensive performance test (CPT) architecture, including content and requirements.

Track and maintain status of verification activities and schedule dates across the mission.

- Status of verification matrices
- Release of draft & official verification plans for review
- Dates of test readiness review meetings
- Release of verification procedure results for review
- Status of verification discrepancies and resolution processes

Track the progress and status of other working groups with regard to issues affecting verification (for example, I&T Working Group, Mission Operations Working Group, Pointing Working Group, ICD working groups, test discrepancy resolution teams, etc.).

Maintain metrics of mission verification progress (such as TBXs in verification matrices and number of requirements verified).

Maintain a verification archive for use by the flight operations team after hand over.

Sunset

The Verification Working Group will be disbanded after on-orbit observatory hand over. At handover it will deliver its archive of activities to the flight operations team.