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Global Precipitation Measurement (GPM) Systems Engineering Management Plan (SEMP)

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National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

Global Precipitation Measurement (GPM)

Systems Engineering Management Plan (SEMP)

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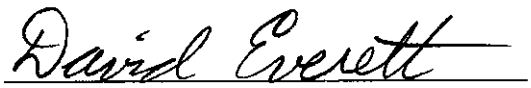

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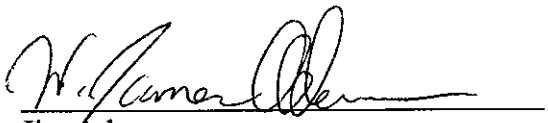

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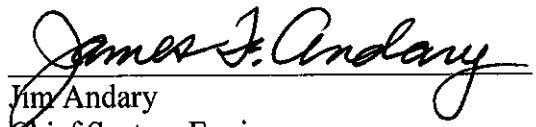

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CHANGE RECORD PAGE

ISSUE	DATE	PAGES AFFECTED	DESCRIPTION
Original	2/1/02	All	Baseline

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LIST OF AFFECTED PAGES

Page #	Revision	Page #	Revision	Page #	Revision	Page #	Revision

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TABLE OF CONTENTS

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1. Introduction

1.1. Document Purpose and Scope

The Global Precipitation Measurement (GPM) Systems Engineering Management Plan (SEMP) defines the technical management approach to manage and execute GPM Systems Engineering activities. This document covers the entire systems engineering life cycle of GPM. However, the SEMP is an evolving document that will be updated to highlight the activities in the current mission phase. This initial release focuses on mission formulation activities while subsequent releases, prior to Preliminary Design Review (PDR), will provide details on activities associated with implementation and operations.

The primary audience of the GPM SEMP is the GPM Systems Engineering Team, consisting of the Mission Systems Engineer (SE), Element SEs, and supporting engineering team members. The SEMP provides guidance to the GPM Systems Engineering Team regarding expectations of them across the life cycle.

1.2. Document Structure

The GPM SEMP is structured to emphasize systems engineering activities in the context of the mission life cycle. As GPM matures in the engineering life cycle, the focus of the systems engineering processes changes. This SEMP emphasizes the evolution of those processes across the critical mission phases as defined by project and engineering control gates.

The final products of GPM Systems Engineering are the operationally generated science data products. To monitor progress along the way, the SEMP defines intermediate outputs of the systems engineering process such as documents and briefings for review and approval.

1.3. Applicable Documents

Formulation Authorization Document for the Global Precipitation Measurement, Draft Revision 8, November 9, 2001

GPM Level 1 Requirements, Draft Revision 8, October 15, 2001

Global Precipitation Measurement (GPM) Project Formulation Plan, 420-10-01, November 15, 2001

NASA Program and Project Management Processes and Requirements, NPG 7120.5A, NASA Procedures and Guidelines, April 3, 1998

GSFC Project Formulation, 700-PG-7120.2.2A, NASA Procedures and Guidelines, August 6, 1999

NASA Systems Engineering Handbook, National Aeronautics and Space Administration, June 1995

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2. GPM Background

The GPM Mission is being formulated within the context of the Global Water and Energy Cycle initiative with the foremost science objectives focusing on improved climate predictions, improved weather predictions, and improved global water cycle predictions. Exhibit 2-1 shows the GPM science objectives, how they are linked to the larger Earth Science Enterprise mission, and the resulting GPM science drivers.

Exhibit 2-1. GPM Mission Traceability

Earth Science Enterprise Mission	GPM Objectives	GPM Science Drivers
Develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations.	**Climate Prediction** – to improve climate prediction through progress in quantifying space-time variability of precipitation along with improvements in achieving water budget closure, plus focused research on relationships between precipitation and climate variations	• **Global Coverage** – global rain rates at 3- hour observation cycle and 500 x 500 km resolution. • **Latency** - Deliver near real-time and 3- hour products. • **Accuracy Threshold** - Bias error <5%. • **Precision Threshold** - <25%. • **Measure** 4-D structure of rainfall rates and drop size distribution.
	Weather Prediction – to improve the accuracy of global and regional numerical weather prediction models through accurate and precise measurements of instantaneous rain rates, made frequently and with global distribution, plus focused research on more advanced techniques in satellite rainfall data assimilation	
	Flood/Fresh Water Resource Prediction - to improve flood and fresh water resource prediction through frequent sampling and complete Earth coverage of high-resolution precipitation measurements, plus focused research on more innovative designs in hydro-meteorological modeling.	

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

2.1. GPM Architecture Overview

The GPM architecture consists of a collection of U.S. government and international assets. The GPM spacecraft constellation includes one primary science spacecraft and a series of constellation spacecraft for space based precipitation measurements. The primary spacecraft communicates via the Tracking and Data Relay Satellite System (TDRSS) and is controlled via a NASA Mission Operations Center (MOC). Partner spacecraft communicate primarily via partner-controlled assets. Ground based precipitation measurements are made through a set of ground validation and calibration sites. All science data streams provided by the primary spacecraft, constellation spacecraft and ground validation sites are processed by the Global Precipitation Data Processing Center. Exhibit 2-2 illustrates a preliminary GPM program architecture.

Within this context, NASA is directly responsible for developing the primary spacecraft, one constellation spacecraft, the MOC for both spacecraft, the Global Precipitation Data Processing Center, and three ground calibration and validation sites. The launch elements currently exist, and the other elements will be obtained through partnership agreements. This SEMP addresses how the GPM Systems Engineering Team develops the elements they are responsible for, defines partner element interfaces, and identifies integration issues.

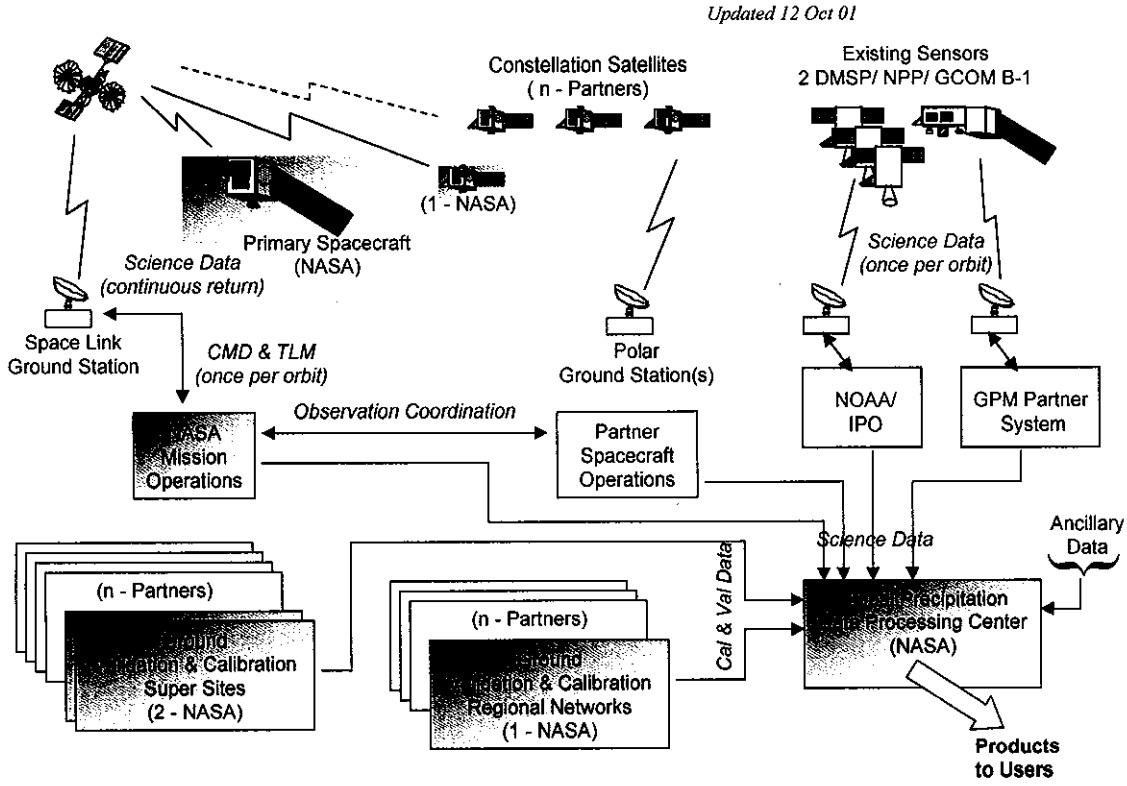

Exhibit 2-2. Preliminary GPM Architecture

2.2. Architecture Hierarchy

Exhibit 2-3 illustrates the GPM Architecture Hierarchy. The remainder of this document utilizes the following terminology when discussing the hierarchy of the GPM Architecture:

- Mission Level
- Segment Level
- Element Level
- Subsystem Level.

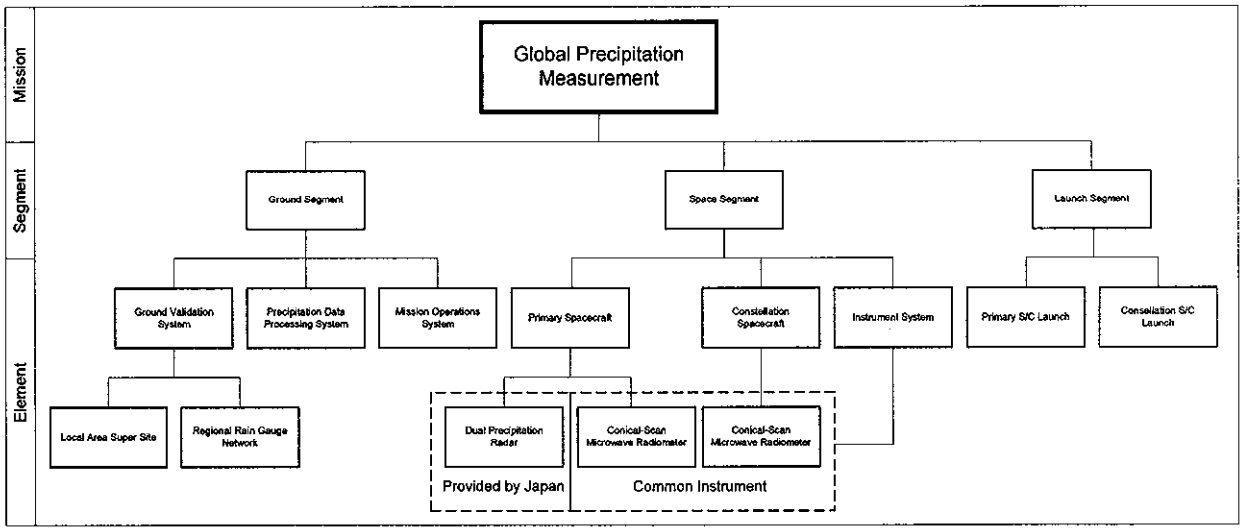

Exhibit 2-3. GPM Architecture Hierarchy

2.3. Requirements Hierarchy

The GPM Systems Engineering Team generates mission requirements through an iterative process that captures additional architecture detail with each engineering phase. GPM requirements describe the architecture and interactions among its pieces in the following manner:

- **Level 1 Requirements** define the successful conduct of the mission. Level 1 Requirements cannot be changed without the approval of an Earth Science Enterprise Configuration Control Board.
- **Mission (Level 2) Requirements** define the mission elements that meet the Level 1 requirements and the interactions between those elements. Those design decisions that impact other elements are defined.
- **Element (Level 3) Requirements** define the subsystems that meet the Mission (Level 2) Requirements and the Level 1 Requirements and the interactions between those subsystems. Those design decisions that impact other subsystems are defined.
- **Subsystem (Level 4) Level** define the components that meet the Level 3 Requirements and higher and the interactions between those components.
- **Interface Control Documents (ICD)** define the detailed interface specifications between the subsystems and components.

2.4. Program Review and Schedule

The GPM Mission Life Cycle will be executed in accordance with NPG 7120.5A Program and Project Management Processes and Requirements. GPM utilizes a Project Formulation Schedule to assist in schedule analysis and monthly reporting to GSFC Center Management. The schedule identifies key activities, or "control points", that are agreed upon between the Project Manager and GSFC Center Management prior to schedule baselining. Significant systems engineering milestones and reviews are contained in the GPM Project Formulation Schedule.

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3. GPM Systems Engineering Overview

GPM Systems Engineering focuses on communications among the engineering teams and is firmly based on the foundations provided in NPG 7120.5A, NASA Program and Project Management Processes and Requirements, as evident through clear definition of the System Analysis, defined interfaces with Project Planning Activities, and established Project Evaluation Guidelines. Systems engineering is the process of dividing a large problem into a system of smaller, more manageable elements. Each element becomes the focus of an Element SE who may divide the element into smaller units for the element engineering teams to address. The challenge is ensuring that all of the elements come together to meet the original project goals. Communications among the elements of the decomposed system is critical to the success of the mission as a whole. This SEMP describes how GPM executes the systems engineering activities while enabling effective integration across mission elements. Effective interactions promote a team-wide understanding of element boundaries and enhance the team's ability to identify subsystem issues that impact other elements.

3.1. Systems Engineering Team and Interactions

The GPM Systems Engineering Team consists of the Mission SE, the Element SEs, and supporting engineering team members. This section highlights their roles, responsibilities, and interactions.

The Mission SE is the overall technical lead for GPM. The Mission SE works with the GPM Project Scientist and Systems Engineering Team to define mission architecture and top-level requirements. The Mission SE ensures that the GPM system meets the science objective of the project. The Mission SE interfaces with the science community and the GPM Instrument SE to ensure science objectives are accurately captured in the requirements.

Element SEs are assigned to each element identified in Exhibit 2-3, with exception of the Launch elements. The Element SEs are responsible for element specific systems engineering activities throughout the mission life cycle, including element and subsystem requirements development, verification and validation; architecture integration; interface definition; and fabrication. Each Element SE must perform engineering trades and present potential options to the Mission SE and the science community for approval. Unique, element specific responsibilities are defined below.

The Ground Validation SE is responsible for all technical aspects of the Ground Validation System, including the Local Area Super Sites and the Regional Rain Gauge Networks. The Ground Validation SE is also responsible the coordination and alignment of ground validation system partners.

The Precipitation Data Processing SE is responsible for all technical aspects of the Precipitation Data Processing System (PDPS) Element and its interface with the Distributed Active Archive Center (DAAC). The Precipitation Data Processing SE also coordinates with the various international partners providing data streams to define science data agreements.

The Mission Operations SE is responsible for all technical aspects of the Mission Operations System Element including the MOC, space to ground data transport and terrestrial data transport. The Mission Operations SE also coordinates operations preparations and maintenance.

The Primary Spacecraft SE is responsible for all technical aspects of the Primary Spacecraft Element, including spacecraft hardware, software and spacecraft ground support equipment. The Primary Spacecraft SE also coordinates with the Instrument SE to present the science community with potential engineering options to meet science objectives.

The Constellation Spacecraft SE is responsible for preparing the Constellation Spacecraft Element requirements for spacecraft procurement and overseeing the spacecraft acquisition. The Constellation Spacecraft SE interfaces with the spacecraft manufacturer to ensure requirements validation.

The Instrument SE is responsible for all technical aspects of the Primary and Constellation Spacecraft Instrument Subsystems, including instrument hardware, software, and instrument ground support equipment. The Instrument SE is the primary interface to the science community to ensure that science objectives are accurately captured by the instrument requirements.

3.2. Systems Engineering Process Overview

Three categories of activities are performed across the life cycle of the mission: Systems Engineering Activities, Enabling Activities, and Engineering Management and Control Activities.

Systems Engineering Activities are those activities that are executed by the GPM Systems Engineering Team. The GPM Systems Engineering Team iterates these activities across all mission life cycle phases. The emphasis of the activities matures as the mission proceeds through the life cycle while the systems engineering processes continue to be executed. Systems Engineering Activities include:

- Concept Development
- Requirements Development
- Architecture Design
- Build
- Integration
- Validation and Verification
- Operations and Maintenance.

Enabling Activities promote effective communication and process execution. Enabling Activities are executed in every life cycle phase in support of the Systems Engineering Activities and include:

- Trade Studies
- Peer Reviews
- Communications.

Engineering Management and Control Activities are cross-cutting, support processes used to track engineering activities across the entire life cycle and include:

- Risk Management
- Reliability Assessment
- Configuration Management.

Exhibit 3-1 summarizes these activities. Additionally, Exhibit 3-1 details the focus of the GPM Systems Engineering Team regarding each of the activities described above for each of the major engineering phases.

		Formulation		Implementation		Operations
Control Gates	Mission Integrated Ops Primary Spacecraft		SRR	PDR	CDR	MOR, FOR, ORR, Pre-Env, Pre-Ship
Systems Engineering Activities	Concept Development	- Baseline Operations Concept	- Detailed Element Concept Development	- Detailed Subsystem Concept Development		
	Requirements Development	- Mission L2 Reqs Development - Preliminary Resource Budgets - Preliminary Element Interface Descriptions	- Element L3 Reqs Development - Subsystem L4 Reqs Development - Baseline Resource Budgets - Subsystem ICDs	- Resource Budgets	- Define Configuration Requirements/ Data Dictionary	- Operational Feedback to Requirements
	Architecture Design	- Functional Element Architecture	- Functional Subsystem Architecture	- Physical Component Architecture - Physical Schematic Architecture		
	Build	- Consider during requirements development	- Identification of long lead production items	- Prototype and demonstration - Initiate acquisition for long lead production items	- Develop and integrate components	- As Built Documentation
	Integration	- Consider I&T during requirements development	- Preliminary I&T Plan	- I&T Plan	- Execute I&T for Prime S/C, Ground Systems, GVS, and SDPS	- Assess I&T Process
	Validation & Verification	- Define Verification Strategy	- Validate L2 Requirements (Is the correct system being designed?) - Baseline Verification Method/Plan	- I&T Plan - Validate L3/L4 Requirements	- Verify System Against Requirements (Has the correct system been built?) - Track Resource Budgets	- Validate L1 Requirements (Is the mission successful?) - Verify Models vs. Operational Data - Resource Budget Feedback
	Operations & Maintenance	- Consider O&M during requirements development	- Preliminary Operations Plan	- Mission Operations Plan - Draft Procedures - Contingency Plans	- Simulation Support - Procedure Finalization and Validation	- Operations - Anomaly Resolution - Data Processing and Delivery
Enabling Activities	Trade Studies	- Operations Concept Trades - Element Requirements Trades - Architecture Trades	- Subsystem Requirements Trades - Architecture Trades	- Operations Architecture Trades		
	Peer Reviews (Mission SE and Element)	- Support System Definition and Team definition	- Support Component-level Decision	- Focus on Operations and Mission Integration	- Focus on Prime S/C I&T - Operations Readiness - Ground Validation Site Performance	- Assess Process
	Communications	- Define engineering teams - Establish Toolset for Req, Arch, Knowledge Capture, Mod & Sim	- Focus on element requirements, architecture, subsystem interfaces - SLATE Prime for Req and Arch	- Component definition and detailed design	- Focus on Systems Integration	- Assess Process
Engineering Management and Control	Risk Management	- Define Risk Management Process - Define Risk Assessment Process - Identify Mission, Element Level Risks	- Identify Subsystem Level Risks - Define Mitigation Techniques - Track Risks and Mitigation	- Identify Component Level Risks - Track Risks and Mitigation - Retire Risks	- Retire Risks	- Track Operational Risks
	Reliability Assessment	- Consider Reliability during requirements development	- Preliminary Reliability assessment at component level	- Validate against reliability requirements	- Test against reliability requirements	- Verify Reliability Models against Operational Data
	Configuration Management	- Define CM Process - Establish CM in Requirements and Trades	- Establish CM in Architecture and Reliability	- Establish CM in I&T processes	- Establish CM in Operations processes	- Assess Process

Exhibit 3-1. GPM Systems Engineering Process Overview

4. Systems Engineering Activities

The following sections provide additional detail on the focus of the GPM Systems Engineering Team during the mission lifecycle. Each Systems Engineering Activity is highlighted and expectations of the Mission SE and Element SEs are detailed for each of those activities. The following criteria for each of the engineering phases identified in Exhibit 3-1 are identified:

- **Entry Criteria:** Engineering prerequisites required to begin the next engineering phase.
- **Inputs:** Data and documents required to execute the activities of the current engineering phase. These are generated prior to entering the current engineering phase.
- **Exit Criteria:** Objectives and approvals required to complete the engineering phase.
- **Output:** Data and documents resulting from successful process completion during the current mission phase.

4.1. Formulation – Pre-System Requirements Review (SRR)

	Mission Integrated Ops Primary Spacecraft	SRR
Entry Criteria - Code Y Approval of Advanced Studies - Formulation Guidance to Proceed	Concept Development	- Baseline Operations Concept
	Requirements Development	- Mission L2 Reqs Development - Preliminary Resource Budgets - Preliminary Element Interface Descriptions
	Architecture Design	- Functional Element Architecture
Inputs - Formulation Authorization Document - Project Formulation Plan - Advanced Study Results - Preliminary Science Requirements - Draft Level One Requirements	Build	- Consider during requirements development
	Integration	- Consider I&T during requirements development
	Validation & Verification	- Define Verification Strategy
	Operations & Maintenance	- Consider O&M during requirements development

Exit Criteria	Outputs
- SRR Approval - Verified L2 Requirements Flow Down from L1 - Approved Systems Engineering milestones through PDR - Established Configuration Management Infrastructure & Procedure	- Mission Operations Concept Doc - Mission (L2) Req's Doc - Functional Element Architecture Diagrams - Preliminary Element Interface Descriptions - Trade Study Results - Risk Management Plan - SEMP - Life Cycle Cost Estimates - Verification Strategy

Exhibit 4-1. Mission Engineering Process during Pre-SRR Formulation

4.1.1. Concept Development

The GPM Mission SE is responsible for the development of the GPM Operations Concept. The preliminary Operations Concept developed during the Advanced Studies phase is evolved as

further engineering and management decisions are made. The Element SEs perform systems engineering trades and make design decisions that may influence the operations concept. The Element SEs provide inputs based on the trades and design decisions to the Mission SE. The Mission SE uses these inputs to continually modify and refine the Operations Concept and generate the baseline Operations Concept to be reviewed at the SRR.

4.1.2. Requirements Development

The Mission SE is responsible for producing the Mission (Level 2) Requirements. The Mission SE monitors progress and ensures that cross-functional impacts are examined and addressed within the team. The Element SEs are responsible for developing the Mission (Level 2) Requirements for each of their respective elements. The Element SEs use the System Level Automation Tool for Enterprises (SLATE) to input and manage the mission requirements in the requirements database. The Element SEs utilize their engineering teams to perform engineering trades and to develop the detailed requirements. The requirements are reviewed by the Mission SE and GPM Systems Engineering Team. The primary focus of the Element SE is to identify those requirements that drive the design and present solution options to the Mission SE and the science community for those driving requirements needing approval. The Mission (Level 2) Requirements will be completed for review at the SRR.

The Primary and Constellation Spacecraft Element SEs are responsible for determining preliminary resource budgets for the respective spacecraft. The Element SEs utilize their engineering teams to perform these preliminary resource budget calculations. Preliminary resource budgets will be completed for review at the SRR.

The Mission SE is also responsible for development of the element interface descriptions. The Mission SE uses the Element SE provided requirements and architecture design as inputs.

4.1.3. Architecture Design

The Mission SE is responsible for developing the mission architecture in accordance with the Level 1 Requirements. The Mission SE utilizes SLATE to maintain the functional element architecture. The Element SEs provide inputs to the architecture design for each respective element, which are incorporated by the Mission SE into the architecture using SLATE. The architecture design is reviewed by the Mission SE and GPM Systems Engineering Team. Functional element architecture diagrams will be developed for review at the SRR.

4.1.4. Build

The Mission SE ensures that Build activities are considered during the Pre-SRR Formulation Phase. Specific activities are not performed but development drivers must be considered when developing the operations concept, requirements, and architecture.

4.1.5. Integration

The Mission SE ensures that Integration activities are considered during the Pre-SRR Formulation Phase. Specific activities are not performed but integration challenges must be considered when developing the operations concept, requirements, and architecture.

4.1.6. Validation and Verification

The Mission SE is responsible for developing a verification strategy that defines the methods that will be used to verify and validate lower level requirements to higher level requirements, design to requirements, build to design, and operational validation to Level 1 requirements using the ground validation system. The Element SEs provide input to the Mission SE regarding potential verification issues. The verification strategy will be completed for review at the SRR.

4.1.7. Operations and Maintenance

The Mission SE ensures that Operations and Maintenance (O&M) activities are considered during the Pre-SRR Formulation Phase. Specific activities are not performed but must be considered when developing the operations concept, requirements, and architecture.

4.1.8. Team Expectations

	Mission SE	Ground Validation SE	Precipitation Data Processing SE	Mission Operations SE	Primary Spacecraft SE	Constellation Spacecraft SE	Instrument SE
Concept Development	• Lead coordination and development • Modify Ops Concept Document	• Provide Input	• Provide Input	• Provide substantial input	• Provide input	• Provide Input	• Provide Input
Requirements Development	• Provide guidance • Ensure communication • Develop preliminary interface definitions • Make mission level decisions	• Develop L2 Ground Validation System Reqs. • Define reqs. imposed on other elements • Provide preliminary interface input	• Develop L2 PDPS Reqs. • Define reqs. imposed on other elements • Provide preliminary interface input	• Develop L2 Ground Operations Reqs. • Define reqs. imposed on other elements • Provide preliminary interface input	• Develop L2 Primary S/C Reqs. • Define reqs. imposed on other elements • Determine Preliminary Resource Budgets • Provide preliminary interface input	• Develop L2 Constellation S/C Reqs. • Define reqs. imposed on other elements • Provide Preliminary Resource Budgets • Provide preliminary interface input	• Develop L2 Instrument Reqs. • Define reqs. imposed on other elements • Provide preliminary interface input
Architecture Design	• Perform functional architecture design for subsystems	• Provide architecture options	• Provide architecture options	• Provide architecture options	• Provide architecture options	• Provide architecture options	• Provide architecture options
Build	• Ensure team consideration	• Consider element build feasibility	• Consider element build feasibility	• Consider element build feasibility	• Consider element build feasibility	• Consider element build feasibility	• Consider element build feasibility
Integration	• Ensure team consideration	• Consider element testability	• Consider element testability	• Consider element testability	• Consider element testability	• Consider element testability	• Consider element testability
Validation & Verification	• Develop Verification Strategy	• Provide input	• Provide input	• Provide input	• Provide input	• Provide input	• Provide input
Operations & Maintenance	• Ensure team consideration	• Consider O&M	• Consider O&M	• Consider O&M • Provide O&M input to Ops Concept	• Consider O&M	• Consider O&M	• Consider O&M

Exhibit 4-2. Expectations of the GPM Systems Engineering Team during Pre-SRR Formulation

4.2. Formulation – Pre-Preliminary Design Review (PDR)

	Mission Integrated Ops Primary Spacecraft	PDR
Entry Criteria - SRR Approval - Accepted Verification Plan - Approved Systems Engineering milestones through PDR	Concept Development	- Detailed Element Concept Development
	Requirements Development	- Element L3 Reqs Development - Subsystem L4 Reqs Development - Baseline Resource Budgets - Subsystem ICDs
	Architecture Design	- Functional Subsystem Architecture
	Build	- Identification of long lead production items
Inputs - Mission (Level 2) Requirements Document - Operations Concept Document - Functional Subsystem Architecture Diagrams - System Verification Strategy	Integration	- Preliminary I&T Plan
	Validation & Verification	- Validate L2 Requirements (Is the correct system being designed?) - Baseline Verification Method/Plan
	Operations & Maintenance	- Preliminary Operations Plan
		Exit Criteria - Reviewed and Accepted Level 3 & 4 Requirements - Verified L3/L4 Requirements Flow Down from L2 Requirments - PDR Approval - MCR Approval
		Outputs - Element (L3) and Subsystem (L4) Req's Docs - ICDs - Baseline Mission Architecture - Verification Req's Matrix - Baseline Resource Budgets - Cost Estimates - Reliability Program Plan - Updated SEMP

Exhibit 4-3. Mission Engineering Process during Pre-PDR

4.2.1. Concept Development

A Baseline Operations Concept document was created in the previous phase, but ongoing engineering activities may impact that baseline. The Element SEs are responsible for providing any final element modifications to the Operations Concept to the Mission SE, who incorporates any modifications deemed necessary. The Element SEs are also responsible for detailed element level concept development.

4.2.2. Requirements Development

The Mission SE is responsible for coordinating the generation of the Element and Subsystem (Level 3 and Level 4) Requirements. The Mission SE monitors progress and ensures that cross-functional impacts are examined and addressed within the team. The Element SEs are responsible for developing the Element (Level 3) and Subsystem (Level 4) Requirements for each of their respective systems. The Element SEs continue to use SLATE to input and manage the requirements in the requirements database. The Element SEs utilize their engineering teams to perform further engineering trades and to develop the detailed requirements. The

requirements are reviewed by the Mission SE and GPM Systems Engineering Team and will be completed for review at the PDRs.

The Primary and Constellation Spacecraft Element SEs are responsible for determining baseline resource budgets for the respective spacecraft. The preliminary resource budgets have been reviewed at the SRR. The Element SEs utilize their engineering teams to modify the preliminary calculations and perform further analysis for the baseline resource budgets. Baseline resource budgets will be completed for review at the PDRs.

Each Element SE is responsible for development of the Subsystem ICDs. The Element SEs work with the Mission SE to resolve interface issues between elements.

4.2.3. Architecture Design

The Mission SE is responsible for developing the mission architecture in accordance with the Mission, Element, and Subsystem Requirements. The Mission SE utilizes SLATE to perform architecture design and element integration. The Element SEs develop the functional subsystem architectures and make modifications to the architecture design for each respective system using SLATE. The architecture design continues to be reviewed by the Mission SE and GPM Systems Engineering Team. The functional subsystem architectures and baseline mission architecture will be completed for review at the PDRs.

4.2.4. Build

The Mission SE ensures that Build activities are considered during the Pre-PDR Formulation Phase and provides guidance to any ongoing activities. The Constellation Spacecraft and Instrument SEs are responsible for identifying long lead production items that need to be produced or acquired. The other Element SEs continue to consider Build when developing the Element and Subsystem requirements and architecture design.

4.2.5. Integration

The Mission SE develops the preliminary Integration and Test (I&T) Plan. The Element SEs are responsible for providing element level inputs for the plan. The Element SEs continue to consider Integration activities when developing the Element (Level 3) and Subsystem (Level 4) requirements and architecture design.

4.2.6. Validation and Verification

The Mission SE coordinates development of the preliminary Mission Verification Plan and the Verification Requirements Matrix. The verification strategy is used as a basis for the verification plan. The Element SEs are responsible for providing inputs to the Verification Requirements Matrix for the respective elements. The Verification Requirements Matrix is used to verify Mission Level 2 Requirements. The Element SEs validate their designated Mission (Level 2) Requirements to ensure that the GPM Systems Engineering Team is "designing the right system" by PDR. The preliminary Mission Verification Plan and Verification Requirements Matrix for the elements and the mission will be completed for review at the Element PDRs.

4.2.7. Operations and Maintenance

The Mission SE continues to ensure that O&M activities are considered during the Pre-PDR Formulation Phase. The Mission Operations SE develops the preliminary Operations Plan. The other Element SEs provide operations inputs to the Mission Operations SE for inclusion in the plan. The Element SEs also continue to consider O&M activities when developing the Element and Subsystem requirements and architecture design.

4.2.8. Team Expectations

	Mission SE	Ground Validation SE	Precipitation Data Processing SE	Mission Operations SE	Primary Spacecraft SE	Constellation Spacecraft SE	Instrument SE
Concept Development	• Make final modifications to Ops Concept Doc.	• Develop detailed element concepts	• Develop detailed element concepts	• Develop detailed element concepts	• Develop detailed element concepts	• Develop procurement strategy	• Develop detailed element concepts
Requirements Development	• Provide guidance • Ensure communication • Coordinate Subsystem ICD development	• Develop detailed (L3/L4) Ground Validation System Specification • Develop Subsystem ICDs	• Develop detailed (L3/L4) PDPS Specification • Develop Subsystem ICDs	• Develop detailed (L3/L4) Ground Operations Specification • Develop Subsystem ICDs	• Develop detailed (L3/L4) Primary S/C Specification • Determine Primary S/C Baseline Resource Budgets • Develop Subsystem ICDs	• Develop Constellation S/C Reqs. for acquisition • Determine Constellation S/C Baseline Resource Budgets • Develop Subsystem ICDs	• Develop detailed (L3/L4) Instrument Specification • Develop Subsystem ICDs
Architecture Design	• Perform Architecture design & integration for the elements	• Develop physical component architecture	• Develop physical component architecture	• Develop physical component architecture	• Develop physical component architecture	• Develop physical component architecture	• Develop physical component architecture
Build	• Provide guidance • Ensure team consideration	• Consider element build feasibility • Develop Development & Implementation Plan	• Consider element build feasibility • Develop Development & Implementation Plan	• Consider element build feasibility • Develop Development & Implementation Plan	• Identify long lead production items • Develop Development & Implementation Plan	• Consider element build feasibility • Develop Development & Implementation Plan	• Identify long lead production items • Develop Development & Implementation Plan
Integration	• Develop Preliminary I&T Plan	• Provide Input	• Provide Input	• Provide Input	• Provide Input	• Provide Input	• Provide Input
Validation & Verification	• Coordinate development of preliminary Verification Plan • Coordinate development of Valid. Reqs. Matrix	• Develop preliminary Element Verification Plan • Develop Validation Reqs. Matrix inputs • Validate L2 Reqs.	• Develop preliminary Element Verification Plan • Develop Validation Reqs. Matrix inputs • Validate L2 Reqs.	• Develop preliminary Element Verification Plan • Develop Validation Reqs. Matrix inputs • Validate L2 Reqs.	• Develop preliminary Element Verification Plan • Develop Validation Reqs. Matrix inputs • Validate L2 Reqs.	• Develop preliminary Acceptance Plan • Develop Validation Reqs. Matrix inputs • Validate L2 Reqs.	• Develop preliminary Element Verification Plan • Develop Validation Reqs. Matrix inputs • Validate L2 Reqs.
Operations & Maintenance	• Ensure team consideration	• Consider O&M • Provide Inputs	• Consider O&M • Provide Inputs	• Develop preliminary Operations Plan	• Consider O&M • Provide Inputs	• Consider O&M • Provide Inputs	• Consider O&M

Exhibit 4-4. Expectations of the GPM Systems Engineering Team during Pre-PDR Formulation

4.3. Implementation – Pre-Critical Design Review (CDR)

	Mission Integrated Ops Primary Spacecraft	◇ CDR
Entry Criteria -	Concept Development	- Detailed Subsystem Concept Development
	Requirements Development	- Resource Budgets
	Architecture Design	- Physical Component Architecture - Physical Schematic Architecture
	Build	- Prototype and demonstration - Initiate acquisition for long lead productions items
Inputs -	Integration	- I&T Plan
	Validation & Verification	- I&T Plan - Validate L3/L4 Requirements
	Operations & Maintenance	- Mission Operations Plan - Draft Procedures - Contingency Plans

Exit Criteria -
Outputs -

Exhibit 4-5 Mission Engineering Process during Pre-CDR Implementation

Pre-CDR Mission Engineering Activities occur in the implementation phase. These activities will be developed in a later version of the GPM SEMP as this current publication focuses on Formulation activities.

4.4. Implementation – Pre-Operations Readiness Review (ORR)

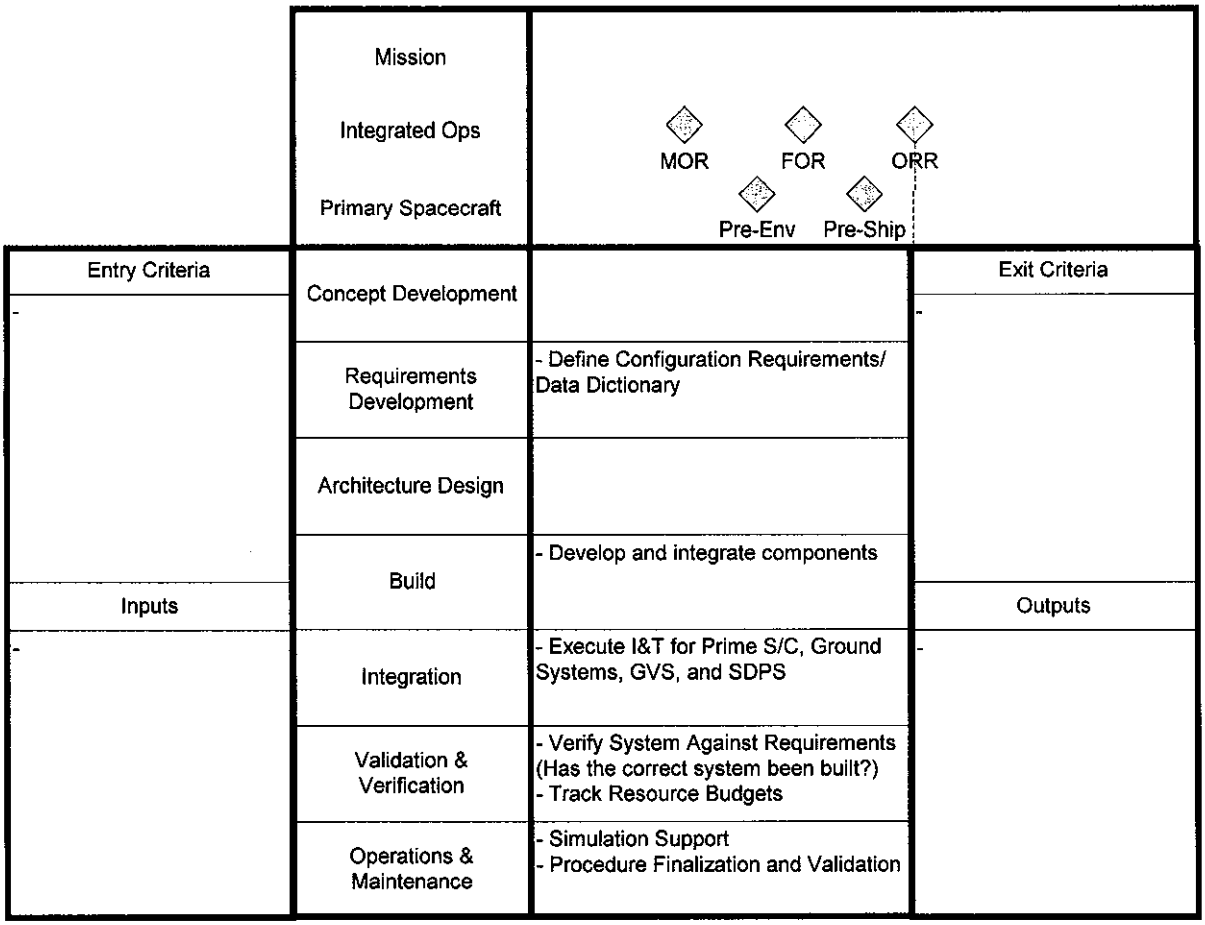

Exhibit 4-6. Mission Engineering Process during Pre-ORR Implementation

Pre-ORR Mission Engineering Activities occur in the implementation phase. These activities will be developed in a later version of the GPM SEMP as this current publication focuses on Formulation activities.

4.5. Operations – Post-ORR

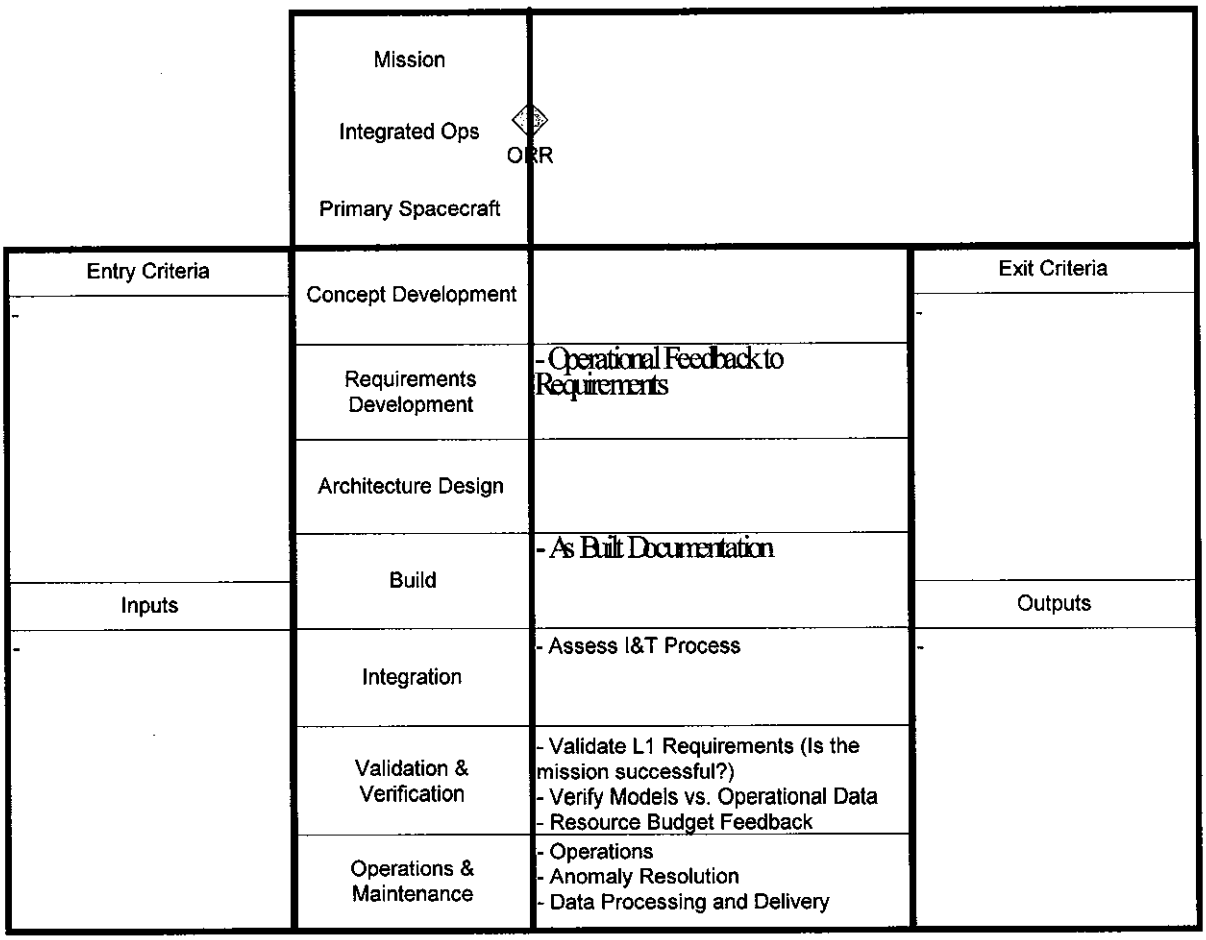

Exhibit 4-7 Mission Engineering Process during Post-ORR Operations

Post-ORR Mission Engineering Activities occur in the operations phase. These activities will be developed in a later version of the GPM SEMP as this current publication focuses on Formulation activities.

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5. Enabling Activities

5.1. Trade Studies

Trade studies provide the ability to make reasonably complex decisions involving multiple alternatives evaluated against a set of engineering, performance, cost, schedule, supportability, and risk criteria. Trade studies are performed as objective evaluations of alternative requirements, architectures, design approaches, system improvements, or other engineering actions using predefined rules and criteria. Trade studies can be performed at the Mission, Element, or Subsystem level depending on need and phase in the mission life cycle. Trade studies are used to assess engineering options and to assist decision makers in the selection of a final option.

The Mission SE is responsible for coordinating trades between Elements, while each Element SE is responsible for performing or coordinating trade studies within their respective element. The Mission SE ensures cross-element communication and makes Mission level decisions. The Element SEs and their engineering teams define the rules and criteria applicable to the specific trade studies. The Element SE coordinates with the Mission SE and Element SEs who may be affected by the engineering decision. The Element SEs are responsible for communicating the study results and recommendations to the GPM Systems Engineering Team.

The results and decisions from the various trade studies performed may result in concept and requirements changes. The Element SEs modify the requirements as necessary and notify the Mission SE of Mission Operations Concept changes.

Each trade study is documented, including assumptions, trade space, alternatives evaluated, evaluation criteria, results, and recommendations. All trade study results will be captured in the GPM Knowledge Management System. The trade study results are communicated to the Mission and Element SEs and their teams through the numerous Peer and Engineering Reviews throughout the mission life cycle.

5.2. Peer Reviews

Peer reviews provide guidance and perspective to the GPM Systems Engineering Team and GSFC center management insight to the progress and risk associated with GPM. The GPM Systems Engineering Team participates in Systems Engineering Peer Reviews and Element Peer Reviews.

5.2.1. Systems Engineering Peer Review Process

The Systems Engineering and Advanced Concepts Division (SEACD) selects a peer review panel to follow a mission throughout its life. The Mission SE convenes the peer review panel approximately every 3 months for about 2 hours, where the panel provides guidance and perspective, monitors progress, recommends improvements, and ensures the practice of sound systems engineering. The reviews are informal, tabletop discussions to discuss and critique in-process requirements, architecture designs, and verification plans. The objective of the Systems Engineering Peer Review is to identify and correct problems before significant cost and

schedule impacts are realized. The Mission SE gains from the experience of the review panel members, the panel members gain from observing the innovation of the SE, and management gains insight into the mission progress through the review panel's reports. Additionally, the peer review provides the Mission SE an opportunity to communicate lessons learned and recommendations on the generic Mission Systems Engineering process to the GSFC engineering community.

The peer review panel is responsible for providing guidance and perspective, monitoring progress, recommending improvements, and ensuring the practice of sound systems engineering. The experience base of the peer review panel members enables them to provide insight to management and guidance to the mission.

The Mission SE is responsible for compiling the necessary requirements, architecture designs, trade study results, and verification plans for the peer review, scheduling the peer review, presenting the information to the review team, documenting the action items, and providing lessons learned and feedback to the overall GSFC Systems Engineering Process. The Mission SE utilizes the GPM Knowledge Management System to capture results of the Systems Engineering Peer Reviews.

5.2.2. Element Peer Review Process

Each Element SE is encouraged to hold element specific peer reviews, with similar goals and activities as the Systems Engineering Peer Review, but more focused on the element specific engineering activities. The Element SE selects the peer review team consisting of subject matter experts to support a peer review process for that specific discipline throughout the mission life cycle. For example, the Primary Spacecraft SE may gather a panel of subsystems engineers while the Mission Operations Engineer may gather a panel of operations managers, flight operations team members, and system developers. The peer reviews are scheduled at the discretion of the Element SE in coordination with the Mission SE, approximately every 3 months for about 2 hours. The panel provides subject matter guidance and perspective, monitors progress, recommends improvements, and ensures the practice of sound discipline engineering practices. Similar to the Mission SE peer reviews, the Element Peer review strives to identify and correct problems before significant cost and schedule impacts are realized. The Element SE gains from the experience of the review panel members, the panel members gain from observing the innovation of the Element SE, and management gains insight into the mission progress through the review panel's reports. The element peer reviews provide an opportunity for the subject matter experts to exchange lessons learned to be applied to future mission development.

The peer review panel is responsible for providing guidance and perspective, monitoring progress, and recommending improvements. The experience base of the peer review panel members enables them to provide insight to management and guidance to the mission.

The Element SE is responsible for identifying and inviting the review panel, scheduling the peer review, presenting the information to the review team, documenting the action items, and providing lessons learned and feedback to the GPM Mission SE. The Element SE utilizes the GPM Knowledge Management System to capture results of the Element Engineering Peer Reviews.

5.3. Communications

Systems engineering is largely a series of communication processes. As the owner of the overall view of the system, the Mission SE is the point of contact for all Element SEs as they design, build, integrate, and operate the system. However, the Mission SE should not be a bottleneck for communications. The Mission SE must encourage independent communications among the elements. The Mission SE identifies critical interface issues between elements and ensures that the Element SEs address these issues. It is expected that the Mission SE acts as the representative of the other elements and subsystems when communicating with a particular Element SE.

Requirements documents and ICDs are tools to facilitate the communication between the elements, but less formal human interaction through face-to-face meetings, phone calls, and E-mail is critical to the success of the mission. Element SEs must understand the impact of their engineering decision on the rest of the system, and the Mission SE acts as the focus for that understanding. At the same time, direct communication between Element SEs is encouraged so that the Mission SE is not an obstacle to the flow of ideas and information.

In order to facilitate the flow of information and ideas across the GPM Systems Engineering Team, communications mechanisms are established in the form of specific engineering teams and tools.

5.3.1. Engineering Teams

Engineering teams are established within GPM to facilitate the engineering activities. GPM is establishing a GPM Systems Engineering Team and more focused Element Engineering Teams

The GPM Systems Engineering Team convenes monthly and is led by the Mission SE. Team members include the Mission SE and his supporting organization as well as all Element SEs. The team facilitates communications across the various elements. Element SEs are expected to provide status of engineering activities and to identify issues or cross-element decisions that require Mission SE involvement. The Mission SE identifies actions and captures meeting information in the GPM Knowledge Management System. Additionally, the GPM Systems Engineering Team provides a forum for discussion of science community requirements and desires and the associated impacts to GPM Mission Engineering.

Each of the five Element SEs establishes a team that meets, approximately monthly, to discuss the engineering activities and actions required within that particular phase. Team members include only those engineers working specifically on that element. If required, the engineers from other elements are invited to discuss issues that impact those areas. The engineering teams are responsible for performing the activities, generating the materials and documents, reviewing the materials and documents, and submitting inputs as identified in Section 4 of this document. The engineering teams are:

- Primary Spacecraft Engineering Team
- Constellation Spacecraft Engineering Team
- PDPS Engineering Team
- Mission Operations Engineering Team
- Ground Validation System Engineering Team.

5.3.2. Tools

GPM utilizes several systems engineering and knowledge management tools to additionally facilitate communications among GPM team members, the GSFC management community, and the science community. The tools also provide specific capabilities to the GPM Systems Engineering Team and assist in the execution of the Systems Engineering Activities.

GPM utilizes a design and requirements management tool called SLATE. This tool captures GPM requirements, architectures, and operations concepts. Each Element SE is provided a SLATE client that provides them with access to the SLATE database. They utilize the client to directly input element and subsystem requirements into the database. The Mission SE and supporting SEs utilize SLATE to build the Mission Architecture and to monitor and track requirements inputs. SLATE generates the GPM requirements documents, GPM mission architecture, and operations concept document. SLATE also provides configuration management of the requirements, architecture, and operations concept.

GPM utilizes a Knowledge Management database to capture information and lessons learned from GPM mission development activities. This tool is a primary mechanism for ensuring communications among the GPM team. The GPM Systems Engineering Team utilizes the Knowledge Management system to maintain documentation, minutes, and action items from the engineering team and peer reviews. Additionally, the Knowledge Management system provides configuration management to engineering documentation and trade study results. The Knowledge Management System is a database with a web-based user interface. GPM team members, GSFC Management, and the science community have access to the web page at all times to accommodate rapid knowledge sharing.

6. Engineering Management and Control

6.1. Risk Management

The GPM Systems Engineering Team utilizes the overarching GPM Risk Management Plan (GSFC 421-01-005-01) to provide continuous, systematic, objective, and repeatable risk management, handling, and reporting. Due to the importance of risk management in the GPM Project, risk events are monitored and controlled throughout the lifecycle of the project. The Risk Management Plan provides detailed information on the GPM Risk Management Process. The process incorporates the implementation of mitigation options, risk monitoring, reviews and assessments, and risk reporting. The process supports the risk management approach of providing continuous assessment of what could go wrong and implementing appropriate mitigation options should a risk occur, as well as the assignment of risks to owners who will be responsible for their effective mitigation.

6.2. Reliability Assessment

The GPM Systems Engineering Team utilizes the overarching GPM Reliability Program Plan (GSFC 421-02-012-01), which establishes the basic reliability policies and defines the approaches to ensure the satisfaction of the Level 2, Level 3, and Level 4 GPM reliability, maintainability, and availability requirements. The tailored GPM reliability program permits the (l) identification of problems or deficiencies before they become serious, (2) report of operational or performance issues to the GPM Project Manager and the GPM user community, (3) resolution of those issues that can be resolved in an operation environment, and (4) best use of existing material to support reliability analyses. The Mission SE and the Element SEs work closely with the GPM System Assurance Manager to perform the required analyses and testing. They document reliability performance, while surfacing and correcting any reliability issues.

6.3. Configuration Management

The GPM Systems Engineering Team utilizes the overarching GPM Configuration Management (CM) Process to address configuration identification, control, status accounting, and auditing. The CM process focuses on establishing and controlling baselines; establishing mechanisms for identifying and evaluating the cost, schedule and performance impacts of proposed changes to those baselines; and providing status reporting for all controlled configurations. The GPM CM Plan provides detailed information into the GPM CM Program.

A key CM element is controlling configuration baselines (requirements, software data, and hardware). The GPM Requirements Management System, contained in the automated SLATE requirements management tool, provides the requirements baseline. The GPM Software Engineering System, contained in the To Be Determined (TBD) software engineering tool, contains the software baseline. The GPM Documentation Management System provides the data and hardware (Bills of Materials) baselines. Each GPM Element SE will utilize these tools to manage the requirements, software and hardware configurations for that element. If an Element SE determines that an alternate tool is better suited for configuration management of their element, the recommendation will be presented to the GPM configuration control board for approval. The GSFC Centralized Configuration Management System initially serves as the GPM

Documentation Management System with later transition to a different knowledge management system if needed to support the large GPM user community.

7. Control Gates

7.1. Mission Level Control Gates

7.1.1. System Requirements Review

The SRR focuses on the Mission (Level 2) Requirements. The objective of the SRR is to confirm that the Mission Level Requirements meet the current mission objectives. The SRR ensures that the mission objectives and Level 1 Requirements have been successfully flowed down to Mission (Level 2) Requirements. Additionally, the SRR examines requirements validation and verification criteria, engineering plans to achieve future milestones, and technology development requirements. The SRR results in the baseline Mission (Level 2) requirements document and Project Manager approval to proceed with proposal preparations for project implementation.

The following documents are required for review and approval at the SRR:

- Mission Operations Concept Document
- Mission (Level 2) Requirements Document
- Functional Element Architecture Diagrams
- Preliminary Element Interface Descriptions
- Trade Study Results
- Risk Management Plan
- Systems Engineering Management Plan
- Life Cycle Cost Estimates
- Verification Strategy.

The SRR consists of a formal presentation of the materials listed above during a 1-day session. NASA Headquarters and NASA GSFC Code 300, Office of System Safety and Mission Assurance, work with the Mission SE and the GPM Project Manger coordinate the review panel members

7.1.2. Preliminary Design Review

Preliminary Design Reviews (PDR) are held to demonstrate that the preliminary design meets all system requirements with acceptable risk. Element specific PDRs are held prior to the overall mission PDR covering all the elements from a mission perspective. Following completion of the SRR, the Mission SE and the Element SEs determine which elements require a PDR.

Each of the Element SEs is responsible for coordinating the element PDR. The objective of the PDR is to demonstrate that the preliminary design is sufficient to proceed to detailed design. The Element SE demonstrates that the appropriate design option has been selected by presenting key trade study analyses and results. The PDR verifies that all Mission (Level 2) Requirements have been successfully flowed down to the Element (Level 3) and Subsystem (Level 4) requirements and that interface requirements are sufficiently defined. The PDR also

demonstrates that the verification methods have been appropriately defined and that all risks have been identified and mitigated, as necessary.

The following documents are required for review and approval at the PDR:

- Element (Level 3) and Subsystem (Level 4) Requirements Documents
- ICDs
- Baseline Mission Architecture
- Verification Requirements Matrix
- Baseline Resource Budgets
- Cost Estimates
- Reliability Program Plan
- Updated SEMP

Each PDR consists of a formal presentation of the materials listed above during a 1-day session. NASA Headquarters and NASA GSFC Code 300, Office of System Safety and Mission Assurance, work with the Mission SE and the GPM Project Manger coordinate the review panel members. Following completion of the Mission PDR, GPM proceeds to the Mission Confirmation Review (MCR) to gain approval to proceed to the implementation phase. The MCR is a Center level review and is discussed in the GPM Formulation Plan.

7.1.3. Critical Design Review

The CDR occurs in the implementation phase, and will be addressed in detail in the next release of the GPM SEMP.

7.2. Integrated Operations Control Gates

Each Integrated Operations Control Gate covers all aspects of the GPM mission, including the GPM elements and partner spacecraft or data streams. They examine the GPM mission as a whole as it prepares for operations. The Integrated Operations Control gates occur in the Implementation Phase of the GPM mission lifecycle, and will be addressed in more detail in the next release of the GPM SEMP. As of the publication date of this document, the following integrate operations Control Gates have been identified:

- Mission Operations Review
- Flight Operations Review
- Operations Readiness Review

7.3. Primary Spacecraft Control Gates

The Primary Spacecraft Control Gates are GSFC specific reviews for the GSFC developed Primary Spacecraft. They examine the readiness of the primary spacecraft as it proceeds through fabrication and shipment. The Primary Spacecraft Control Gates occur in the Implementation Phase of the GPM mission lifecycle, and will be addressed in more detail in the next release of the GPM SEMP. As of the publication date of this document, the following Primary Spacecraft Control Gates have been identified:

- Pre-Environmental Review
- Pre-Ship Review

Appendix A – Acronyms

CDR	Critical Design Review
CM	Configuration Management
CMD	Command
DAAC	Distributed Active Archive Center
DMSP	Defense Meteorological Support Program
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center
GVS	Ground Validation Sites
I&T	Integration and Test
ICD	Interface Control Document
IPO	Integrated Program Office
MCR	Mission Confirmation Review
MOC	Mission Operations Center
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
O&M	Operations & Maintenance
ORR	Operations Readiness Review
PDPS	Precipitation Data Processing System
PDR	Preliminary Design Review
S/C	Spacecraft

SE	Systems Engineer
SEACD	Systems Engineering and Advanced Concepts Division
SEMP	Systems Engineering Management Plan
SRR	Systems Requirements Review
SLATE	System Level Automation Tool for Enterprises
TDRSS	Tracking and Data Relay Satellite System
TLM	Telemetry