Goddard Procedural Requirements (GPR)

DIRECTIVE NO.	GPR 7123.1A	**APPROVED BY Signature:**	***Original signed by Arthur F. Obenschain for***
EFFECTIVE DATE:	August 16, 2010	**NAME:**	Robert Strain
EXPIRATION DATE:	August 16, 2015	**TITLE:**	Director

COMPLIANCE IS MANDATORY

Responsible Office: 599/Mission Systems Engineering Branch

Title: Systems Engineering

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PREFACE

P.1 PURPOSE

This directive outlines a process for the systems engineering of Goddard Space Flight Center (GSFC) Missions. The intent is to outline a set of requirements that provide a consistent method for performing systems engineering across GSFC projects. The requirements for systems engineering outlined in this directive are universal principles that, when followed, should result in sound systems.

This directive implements NPR 7123.1, NASA Systems Engineering Processes and Requirements as tailored and refined to support the GSFC mission. The GSFC NPR 7123.1 Implementation Plan (599-IP-100) addresses the compliance and plan to achieve compliance with the 57 requirements contained in the NPR 7123.1. The GSFC Center Survey (599-SUR-100) addresses the 17 "Best Practices" and their associated activities to demonstrate traceability to GSFC processes being used.

This directive defines the minimum set of systems engineering functions for GSFC Missions. These functions, from a product perspective, are defined and described. All phases of the mission life-cycle, and systems of interest, from mission, through major system element, to subsystem, to component or assembly, are considered. The systems engineering functions described in this directive are intended to apply to all systems development at GSFC. What varies from project to project is who performs each activity, to what degree they are performed, and the level of customer insight as to how the functions are accomplished.

This directive is concerned with what practices must be performed, along with insight into why it is required and considered good systems engineering practices, rather than how it is done. The required functions are described by *shall* statements in this GPR and are referenced by "R-#" in front of each required function. A summary of all required functions is listed in Appendix C. The referenced NASA Systems Engineering Handbook, SP-2007-6105, provides detailed guidance on how to perform systems engineering functions. Tailoring of how, when, where, and by whom these functions are performed is described in a project unique Systems Engineering Management Plan (SEMP). The suggested SEMP outline, including annotation, is provided in Appendix D.

Principles for tailoring systems engineering activities are listed in Appendix E. The tailoring guidelines address who performs the functions and to what degree the functions are performed.

This directive defines systems engineering terminology (Appendix A). Roles and Responsibilities (Section 1) and the systems engineering life-cycle (Section 2) are defined. Systems Engineering Management is discussed in Section 3, which includes a discussion of the necessary technical team communications and the systems engineering team. Systems engineering functions and products, and critical function flow and process operations, are discussed in Section 4. System Milestones and Products are discussed in Section 5. Appendix C contains a list of the systems engineering requirements defined within this directive. It may be used as a sample validation matrix.

P.2 APPLICABILITY

R-1 *This GPR shall be applied to all GSFC managed Flight Systems & Ground Support (FS&GS) projects that are required to follow NPR 7120.5, NASA Space Flight Program and Project Management Requirements.*

This GPR applies to all missions (i.e., programs/projects) for which GSFC is responsible, as well as to deliverable instruments, spacecraft and other GSFC mission products. It applies to all NPR 7120.5 applicable projects/programs such as concept studies, mission formulation, and implementation sub-processes, including mission operations, decommissioning and disposal.

R-2 *The following projects shall be excluded from the application of this GPR: Basic and Applied Research (BAR), Advanced Technology Development (ATD), Institutional Projects (IP), and Institutional Information Technology (IT) Projects.*

R-3 *For systems that contain software, the mission team shall ensure that software acquired or developed internally within NASA complies with NPD 2820.1, NASA Software Policy, and NPR 7150.2, NASA Software Engineering Requirements.*

This GPR applies to each project going forward from the current state of the project's life-cycle. There is no intent to require retroactive compliance with activities that have already occurred in the project's life-cycle.

P.2.1 Applicability to Mission Classification

Four risk levels or classifications for NASA projects (Class A through D) are defined in NPR 8705.4, Risk Classification for NASA Payloads. Although all GSFC-managed FS&GS projects are required to follow this GPR, class C and D missions may tend to permit reduction in procedural requirements to accommodate the limited resources and the higher mission success risks that are typically accepted under these classifications. The reduction in certain processes, however, should put added emphasis on strong systems engineering. A strong systems engineering function is required to provide a depth of knowledge and experience sufficient to mitigate the risks introduced by reducing the procedural requirements. Appendix F gives guidance in selecting the proper level of application for each systems engineering function for each class of mission.

Section 1.0 addresses the Designated Governing Authority (DGA) and the tailoring/waiver approval for SEMP development.

P.2.2 Applicability to Contracted Effort

When work is performed via contracts, each project needs to make clear the delineation of responsibility between contractors and customers, and the degree of insight, verification and approval authority of the customer. It is critical that the statements of work (SOW) include the required systems engineering activities and deliverable products that provide customer insight into progress and results. Further discussion of the application of systems engineering process to contractor efforts is discussed in Appendix E, section C.2.

P.3 AUTHORITY

a. NPR 7123.1, NASA Systems Engineering Processes and Requirements

P.4 APPLICABLE DOCUMENTS

a. NPD 2820.1, NASA Software Policy

b. NPR 7150.2, NASA Software Engineering Requirements

c. NPR 8705.4, Risk Classification for NASA Payloads

d. NPR 8705.5 Probabilistic Risk Assessment (PRA) Procedures for NASA Programs and Projects

e. NPR 8715.6, NASA Procedural Requirements for Limiting Orbital Debris

f. GPR 1410.2, Configuration Management

g. GPR 5340.2, Control Of Nonconformances

h. GPR 7120.4, Risk Management

i. GPR 8700.4, Integrated Independent Reviews

j. GPR 8700.6, Engineering Peer Reviews

k. GSFC-STD-1000, Goddard Space Flight Center Rules for the Design, Development, Verification, and Operation of Flight Systems

l. GSFC-STD-1001, Criteria for Flight and Flight Support Systems Development Lifecycle Reviews

m. GSFC-STD-7000, General Environmental Verification Specification (GEVS)

n. JSC 49040, NASA Systems Engineering Process

o. NASA/SP-2007-6105, NASA Systems Engineering Handbook

p. NASA-STD-7009, Standards for Models and Simulations

q. 599-SUR-100, GSFC System Engineering 7123.1A Center Survey

r. 599-IP-100, GSFC System Engineering 7123.1A Implementation Plan

P.5 CANCELLATION

GPR 7123.1, Systems Engineering

P.6 SAFETY

None

P.7 TRAINING

Training for Systems Engineering is available. The Office of Human Capital Management maintains information on regular and special offerings in systems engineering and related areas.

P.8 RECORDS

Record Title	Record Custodian	Retention
Systems Engineering Management Plans (SEMPs)	Designated Governing Authority (599 Mission Systems Engineering Branch Head)	*NRRS 8/5A1: Permanent Records may be retired to a Federal Records Center when 2 years old. Transfer to National Archives and Records Administration 15 years after completion of the project or when 25 years old, whichever is sooner.

**NRRS – NASA Records Retention Schedules (NPR 1441.1)*

P.9 MEASUREMENT/VERIFICATION

None

PROCEDURES

In this document, a requirement is identified by "shall," a good practice by "should," permission by "may" or "can," expectation by "will," and descriptive material by "is."

1 ROLES AND RESPONSIBILITIES

The Designated Governing Authority (DGA) is primarily responsible for evaluating the technical content of a particular program or project to ensure that it meets the commitments specified in the key management documents. The DGA has signature approval on the Systems Engineering Management Plans and signature approval of waivers against GPR 7123.1 requirements. Due to the number and variety of projects at GSFC, the Center Director hereby delegates the day-to-day activities including signature approval of Systems Engineering Management Plans and GPR 7123.1 waivers to the Director of Applied Engineering and Technology Directorate (AETD) and the officials identified in Table 1. On a case by case basis, the Director of Applied Engineering and Technology Directorate may rescind the delegation from the officials listed in Table 1 below.

Table 1. Designated Governing Authority at GSFC

Project	Delegated DGA Responsibilities
Flight Programs or Projects	Division Chief, Mission Engineering and Systems Analysis and/or Branch Head, Mission Systems Engineering
Instruments	Division Chief, Instrument Systems and Technology and/or Branch Head, Instrument Systems

Systems engineering is the responsibility of all engineers, scientists, and managers working on GSFC missions since they all share in the overall systems engineering effort.

R-4 *For programs and projects involving more than one Center, the lead organization shall develop documentation to describe the hierarchy and reconciliation of center plans implementing NPR 7123.1.*

R-5 *The Product Manager for the systems development function, typically a Study Manager, Project Formulation Manager, Project Manager, or Instrument Manager, shall work with the the DGA to select a Lead Systems Engineer.*

R-6 *The Product Manager and the Lead Systems Engineer shall develop the plan for the systems engineering effort and establish a systems engineering team along with roles and responsibilities.*

R-7 *The DGA or his/her designate shall have responsibility to approve or disapprove any requirement of this document that is either tailored or waived.*

R-8 *The results of Technical Planning, including the associated roles and responsibilities, are captured in the SEMP (Section 4.2.3).*

R-9 *The technical team shall baseline the SEMP prior to the completeion of Phase A and update at each major milestone review or its equivalent. The DGA or designate shall review and approve or disapprove the SEMP at each major milestone review or its equivalent.*

The Lead Systems Engineer (LSE), often referred to as the Mission Systems Engineer (MSE) or Instrument Systems Engineer (ISE), has responsibility for the systems engineering functions and products for the overall mission. Other members of the systems engineering team, discipline, subsystem, or specialty engineers have responsibility for their part of the total effort. Product Development engineers have a responsibility to understand and apply systems engineering functions, as appropriate, to the development of their products. All team members have the responsibility to communicate, coordinate, and validate tasks and products across the mission.

The LSE coordinates the efforts of the systems engineering team. The team recommendations are provided to the Product Manager who makes decisions that balance technical and programmatic performance. For the rest of this directive, the term systems engineer will be used to represent anyone responsible for systems engineering, at any level, as defined above.

2 THE SYSTEMS ENGINEERING LIFE-CYCLE

The project life-cycle is defined as a set of phases: Formulation, Approval, and Implementation. This directive defines systems engineering phases within the familiar Pre-phase A, Phase A, Phase B, Phase C/D, and Phase E/F terminology, described by the NASA Systems Engineering Handbook SP-6105. Each Systems Engineering phase consists of functions and a work flow that produce the products needed for completion of the phase. The mission review is the validating event for the phase and may lead to a revised baseline.

Figure 1, Systems Engineering Functions, shows the interrelationship of the major systems engineering functions described in Section 4. Figure 1 illustrates the recursive nature of the development of a valid concept. In order to reach a complete first solution, all System Lifecycle Functions are inter-related and must be addressed.

Table 2, Systems Engineering Key Functions Matrix, provides a view of the evolution, in maturity and fidelity, of the systems engineering functions over the life-cycle.

Figure 2 shows the Systems Engineering Life-cycle relationship with the project life-cycle and describes the major goal of each phase. Figure 2 also shows the life-cycle phase relationship with critical milestone reviews.

Figure 3 further describes the Formulation Phase.

Figure 4 describes the Implementation Phase.

The life-cycle accommodates the objective of systems engineering by studying multiple approaches in Pre-Phase A, conducting preliminary analysis leading to a single approach in Phase A, completing a preliminary design and validating that the right system has been designed in Phase B, performing a detailed design and verifying that the system is designed right in Phase C, building and verifying the system in Phase D, and operating and disposing it in Phases E and F.

Accomplishing mission objectives requires a consistent set of requirements, design and an operations concept. The operations concept uses the design to meet the requirements. Producing the design and then operating it to meet the requirements must be done within the cost and schedule constraints. Validation, Performance Predictions, Analysis, and Trade Studies are used to develop and optimize the total system.

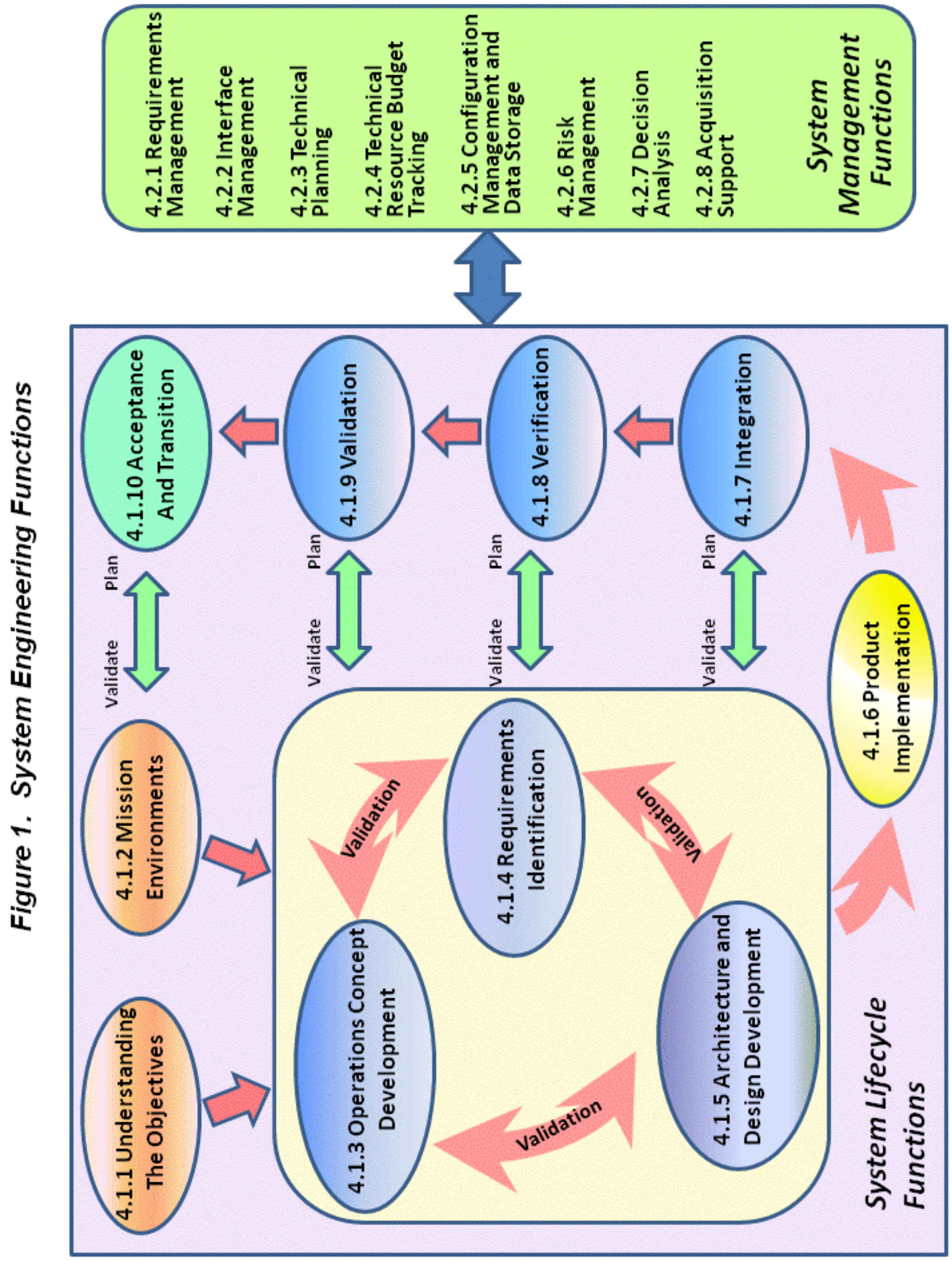

Figure 1. Systems Engineering Functions

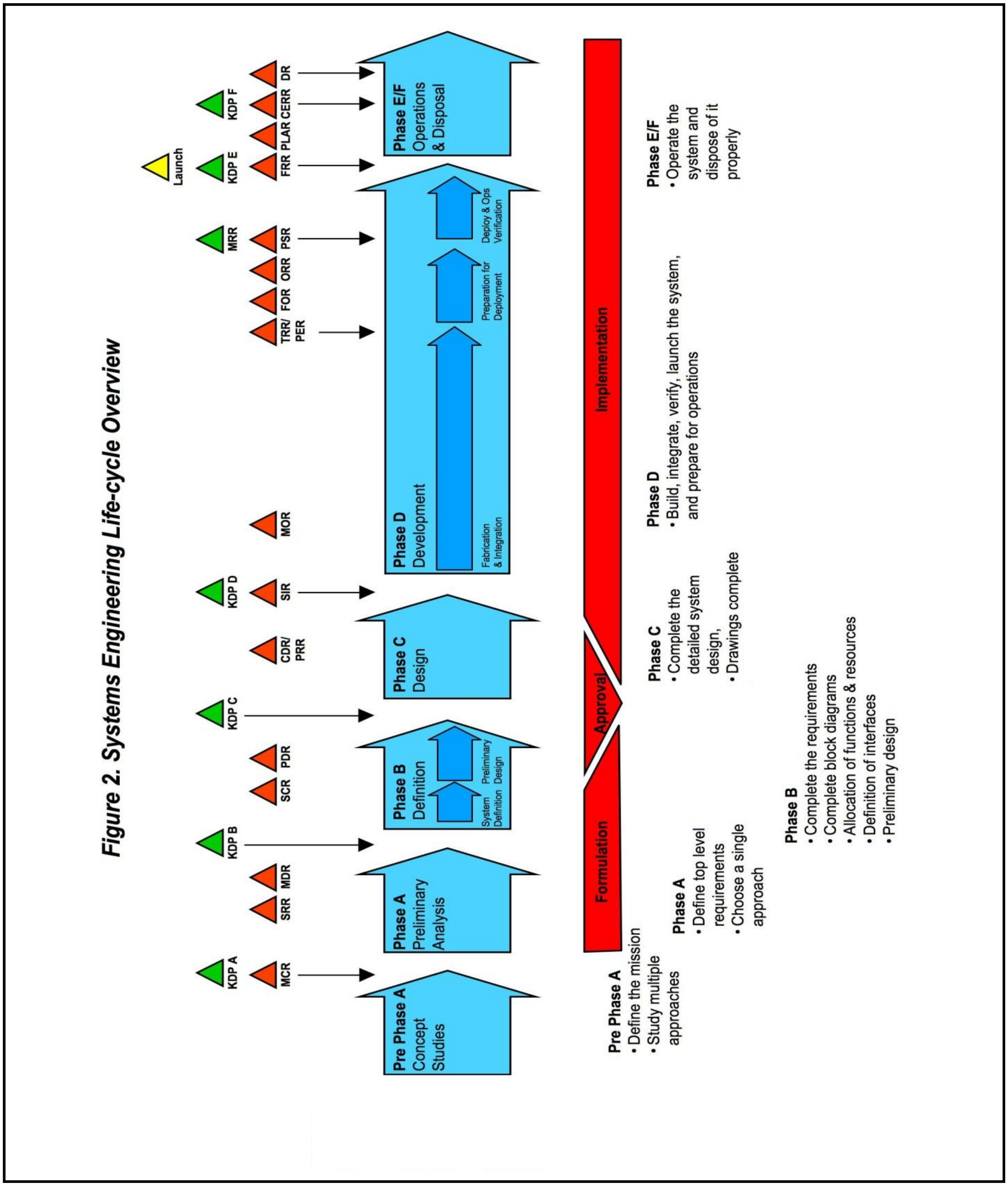

Figure 2. Systems Engineering Life-cycle Overview

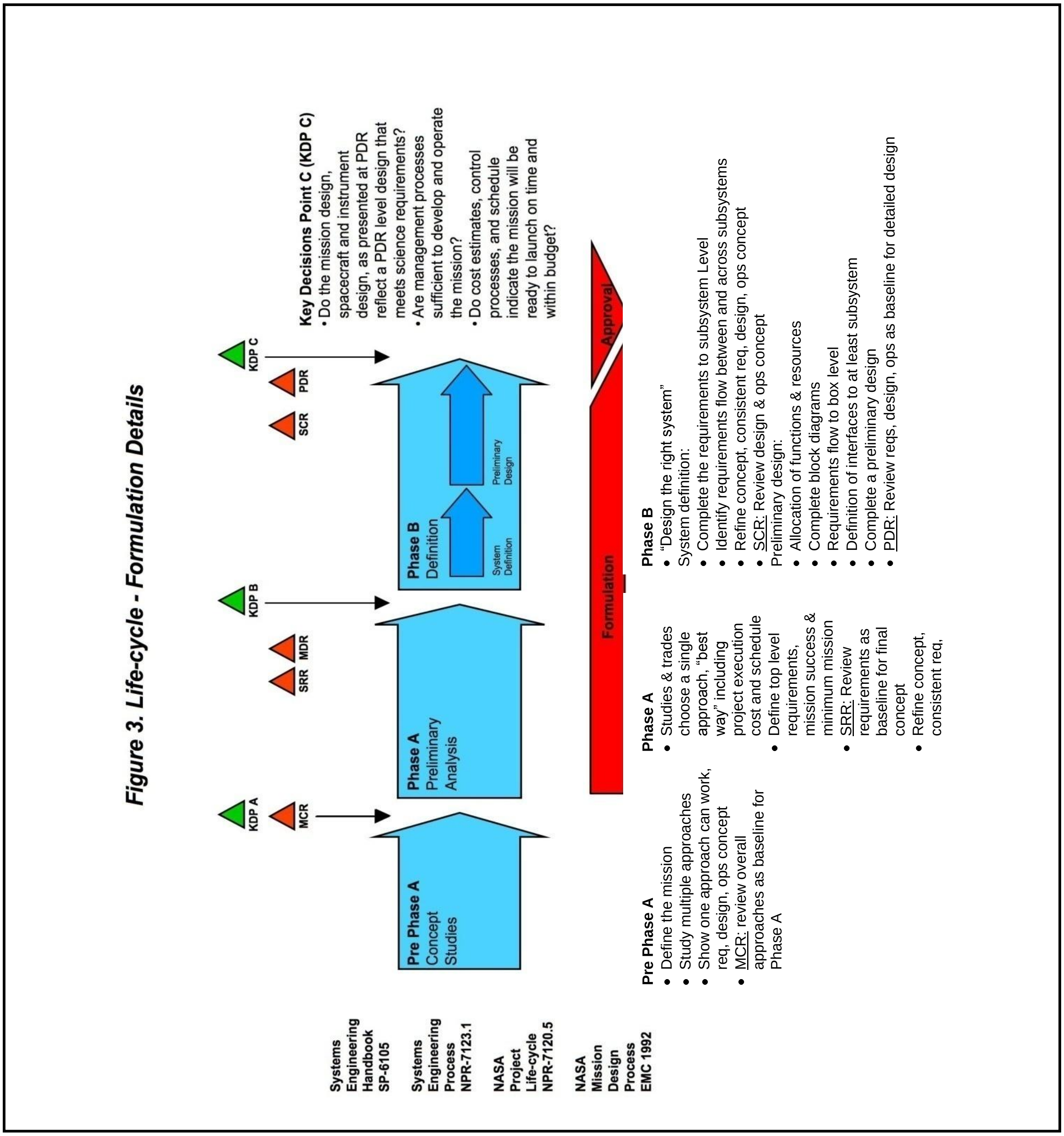

Figure 3. Life-cycle – Formulation Details

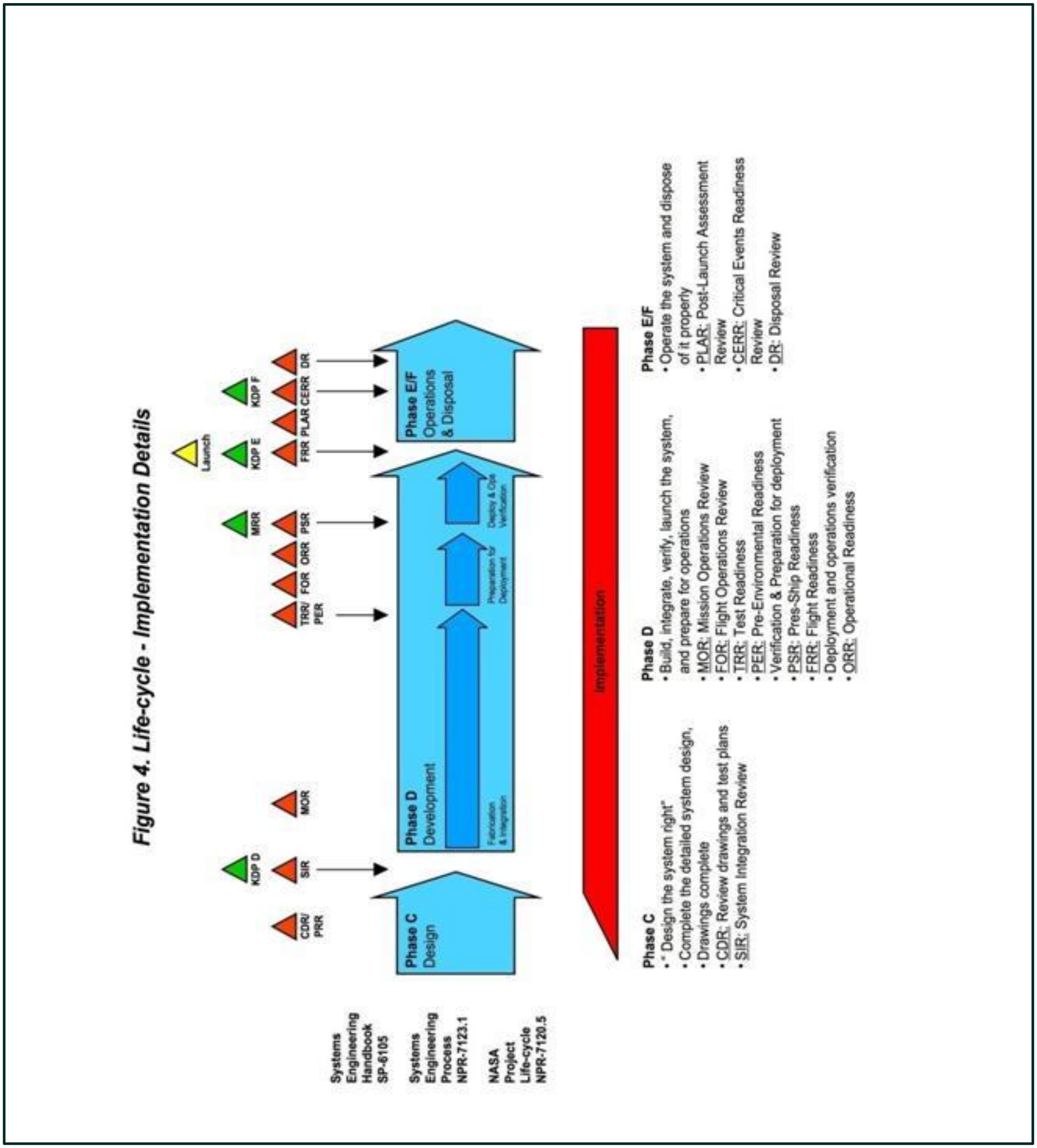

Figure 4. Life-cycle – Implementation Details s

Table 2 - Systems Engineering Key Functions Matrix

Key Function	Where Typically Documented	*Pre-Phase A*	*Phase A*	*Phase B*	*Phase C*	*Phase D*	*Phase E/F*
		Concept Studies	Preliminary Analysis	Definition	Design	Development	Operations
4.1.1 Understanding the Objectives	Level I Requirements Document	Concept	Baseline	Complete (Note 1)	Track Changes	Track Changes	Track Changes
4.1.2 Mission Environments	Environmental Test Plan Orbit Debris Analysis	Initial	Baseline	Complete	Track Changes	Track Changes	Track Changes
4.1.3 Operations Concept Development	Concept of Operations Document Operations Plan	Concept	Baseline	Refine	Complete	Track Changes	Track Changes
4.1.4 Requirements Identification	Level II Requirements Document Level N Requirements Document	Concept	Top Level Baseline	Complete	Track Changes	Track Changes	Track Changes
4.1.5 Architecture & Design Development	Architecture Description Document Design Documentation System Drawings	Concept	Baseline	Complete	Track Changes	Track Changes	Track Changes
4.1.6 Product Implementation	Subsystem Descriptions As-built Documentation		Concept	Concept	Baseline	Complete	
4.1.7 Integration	Integration Plan Integration Procedures	Concept	Concept	Initial	Develop Plans	Complete	
4.1.8 Verification	Verification Plan RVTM	Concept	Initial	Assign Method	Develop Plans	Complete	
4.1.9 Validation	Validation Plan RVTM	Concept	Initial	Assign Method	Develop Plans	Complete	
4.1.10 Product Acceptance & Transition	Acceptance Plan Transition Plan	Concept	Concept	Initial	Baseline	Track Changes	Complete
4.2.1 Requirements Management	Requirements Managemenr Plan (SEMP) Requirements Database	Concept	Baseline	Complete	Track Changes	Track Changes	
4.2.2 Interface Management	IRD's IDD's ICD's	Concept	Initial (Note 2)	Baseline	Complete	Track Changes	
4.2.3 Technical Planning	SEMP	Concept	Initial	Baseline	Complete	Track Changes	
4.2.4 Technical Resource Budget Tracking	Resource Budgets (MSR)	Concept	Initial	Baseline	Track Changes	Track Changes	Track Changes
4.2.5 Configuration Management and Data Storage	CM Plan CM'd Products Technical Data Products	Informal CM	Control Level 1 Requirements	Start Formal CM	Track Changes	Track Changes	Track Changes
4.2.6 Risk Management	Risk Mgmt Plan Risk Database (MSR)	Estimate	Draft FTA, RBD	Preliminary FMEA, 2nd FTA, RBD	Baseline FTA, FMEA, RBD, PRA	Update Changes	Update Changes
4.2.7 Decision Analysis	Trade Study Reports SEMP (Major Trades)	Apply as Needed					
4.2.8 Acquisition Support	SOW, Contract	Develop SOW	Evaluate Proposal(s)	Technical Oversight & Reviews			
5.0 System Milestone Reviews (Note 3)	Review Packages	MCR	SRR, MDR	SCR, PDR,	CDR, SIR	MOR, TRR (PER), FOR, PSR, FRR, ORR, MRR	PLAR, CERR, DR

Note 1: The Level 1 Requirements and Mission Success Criteria (Level I Requirements) must be complete by the end of Phase B.

Note 2: In the case of long-lead items and when instruments are developed early before project is identified, draft ICD's must be written during Phase A.

Note 3: CDR – Critical Design Review, CERR - Critical Event Readiness Review. CR – Confirmation Review, DR – Disposal Review, FOR – Flight Operations Review, FRR – Flight Readiness Review, MCR – Mission Concept Review, MDR – Mission Definition Review, MOR – Mission Operations Review, MRR – Mission Readiness Review, ORR – Operations Readiness Review, PDR – Preliminary Design Review, PER – Pre-Environmental Review, PLAR - Post-Launch Assessment Review, PSR – Pre-Ship Review, SCR – System Concept Review, SIR – System Integration Review, SRR – System Requirements Review, TRR – Test Readiness Review

3 SYSTEMS ENGINEERING MANAGEMENT

The systems engineering effort is distributed across the many system elements that comprise the mission. The coordination of the many disciplines needed to develop, implement, and deliver the elements, and integrate them into an operational system, is both the great challenge and the great reward of systems engineering.

Good systems engineering teams start with a commitment to the delivery of the final product – the successful mission. Such a common focus promotes open communications, consensus building, and a problem solving culture. There is added value in the participation of product engineers in the discovery, development, and allocation of the Mission Design Requirements, architecture and design, and operations concept. Such participation communicates an understanding of the trades, compromises, and optimizations needed to formulate and implement the space mission. The resultant buy-in, by the product leads, results in a focused effort. An advantage of good communications is the collection of the best ideas from the team. Other benefits of open dialog with team members are the reduction of discrepancies, the easier resolution of problems and the improvement in team rapport.

This principle of participation, consensus building, and requirements buy-in is appropriate at all levels, from mission design through assembly and component design. It is the responsibility of systems engineers to foster this philosophy, to support each other through peer reviews, and when called upon, to provide expert advice/guidance in problem solving.

Information needed for the entire spacecraft team, such as the mission space environment, the flight segment electrical system, mechanical system, and thermal system requirements, must be developed and clearly communicated and available to the entire team. The systems engineering information products, expected from each team member, should be clearly defined along with expected delivery dates within each phase of the life cycle.

Methods used include periodic team meetings, concurrent engineering work sessions, email, centralized document control and distribution, peer reviews and formal reviews.

Teamwork is the essence of systems engineering. It is only through the success of the mission team that mission success is achieved.

Communication methods, planned meetings, etc., will be documented and included in the SEMP.

4 KEY SYSTEMS ENGINEERING FUNCTIONS

> "Systems Engineering is a robust approach to the design, creation, and operations of systems", *NASA Systems Engineering Handbook SP6105*

> "The objective of systems engineering is to see to it that the system is designed, built, and operated so that it accomplishes its purpose in the most cost-effective way possible, considering performance, cost, schedule and risk." *NASA Systems Engineering Handbook SP-6105*

This directive seeks to identify the major functions that lay the groundwork for a robust approach. This directive defines key systems engineering functions that are the minimum necessary for GSFC projects.

The following sections describe the functions and define *what* systems engineering functions need to occur and to some degree *when* it should be done. The *when* part is tied to the systems engineering life-cycle and critical project milestones. Implementation of the systems engineering functions, the *where, when*, by *whom*, and *how* is left up to each project to tailor via the Systems Engineering Management Plan (section 6). References such as the SP-6105, JSC-49040, and The NASA Mission Design Process describe approaches to performing these functions.

Mission systems engineering begins with the development of Mission Needs. There are four elements of mission needs. Mission Objectives capture the Science Objectives, along with Programmatic Objectives, and define the overall goals and constraints of the mission. The Measurement Concept defines the science measurements needed to achieve the science objectives. The Payload Concept defines the instrument characteristics, function and performance, needed to make the measurements. And, Mission Design Requirements define the high-level requirements needed to achieve the measurements. These include launch date, mission duration, orbit, and other strategic requirements which drive the Mission Architecture.

Mission Design requires the development of a consistent set of requirements, architectural design and operations concept.

The operations concept uses the design to meet the requirements. Producing the design and then operating it to meet the requirements must be done within the cost and schedule constraints. Trade studies, performance predictions and analysis results are used to optimize a systems requirements, design and operations concept that is tied to the Science Measurement collection objectives and the mission constraints – orbit, thermal power, etc. There are generally several approaches that can work. Determining the optimum is the result of engineering.

The three major systems engineering functions: *Operations Concept Development, Requirements Identification and Architecture & Design Development* flow from the mission needs. These functions, and the resultant products, are interdependent, and must be consistent with each other. The relationship of these three major functions, along with the other key functions, is shown in Figure 1, Systems Engineering Functions. Validation, Performance Predictions, Analysis, and Trade Studies are used to develop and optimize the total system. During the systems engineering life-cycle phases further refinement and definition of the requirements, design and operations concept occurs to lower and lower levels until a detailed design is produced.

The Systems Engineering effort begins during the Pre-Phase A concept study by clearly identifying and understanding the Mission Needs. Multiple approaches for requirements, design and operations concepts are developed, with at least one credibly meeting project objectives and constraints.

During Phase A, analysis activities and trade studies consider multiple approaches. A single approach is chosen for preliminary design in Phase B. Phase B activities seek to allocate the necessary functions to hardware elements and software along with a preliminary design. Phase C takes the allocated functions and produces a design with drawings for production in Phase D.

Phase D verification activities seek to assure that the system elements that are produced actually meet the requirements using the Operations Concept.

Figure 1 shows the relationship between activities performed during the lifecycle in terms of planning and validation. For example, while performing the activity "Understanding the Objectives" planning should be done at the systems level for "Acceptance and Transition" activities and the system team should validate the products generated during the "Understanding the Objectives" phase while performing "Acceptance and Transition" activities, and so on as shown in the diagram. This methodology will assist in completing end-to-end systems engineering

4.1 Systems Lifecycle Functions

4.1.1 Understanding the Objectives

Clearly describing and documenting the *Mission Needs* are important to making sure that the project team is working toward a common goal. The *Science Objectives* and any *New Technology Validation Objectives* form the basis for performing the mission and they need to be clearly defined and articulated. A *Measurement Concept*, that describes the characteristics of the measurements to be made, and a *Payload Concept*, that describes what instrument characteristics are needed to make the measurements, and top-level *Mission Design Requirements*, necessary to achieve the measurements, provide additional basis for mission design. The program constraints, appropriate to the mission, are also captured and used to validate the mission system requirements and later in the lifecycle to validate the mission design. Level 1 requirements represent a contract between the project and headquarters or between a project and the program.

R-10 *Each Project shall work with the stakeholders and the appropriate Enterprise Office at NASA Headquarters to prepare a set of Mission Level 1 Requirements that form the validation basis for the Mission System (Level 2) Requirements.*

Mission Objectives define the mission goals. The Measurement Concept defines the measurements and measurement characteristics that meet the goals. The Payload Concept defines the instrument characteristics needed to achieve the measurements. Mission System Requirements defines the system functions and performance requirements. These four provide a Mission Validation Basis for the mission design.

4.1.2 Mission Environments

Each space mission has a unique set of environmental requirements that apply to all flight segment elements. It is a critical function of systems engineering to define and communicate all the anticipated environments to the team.

4.1.2.1 External Environments

The identified external environments may include Vibration, Shock, Static Loads, Acoustic, Thermal, Humidity, Contamination, Total Dose Radiation, Single Event Effects (SEE), Surface and Internal Charging, Orbital Debris, Atmospheric (atomic oxygen), Attitude Control System (ACS) Disturbance (Atmospheric Drag, Gravity Gradient, Solar Pressure), Magnetic, Radio Frequency (RF) exposure on the ground and on orbit, and man-made threats. Orbital debris and End-of-Mission (EOM) considerations will be addressed in the earlier project life cycle phases – a draft Orbital Debris Analysis (ODA) should be developed by PDR and refined throughout the project's life-cycle phases so that these issues can be properly managed in the Phase F Disposal stage (reference NPR 8715.6 and NASA/SP-2007-6105). For design purposes, it is helpful to have a preliminary concept in place by the MDR so that the supporting element leads can accommodate the plans.

R-11 *Each project shall identify the external environments for the mission, analyze and quantify the expected environment, establish design guidance, and establish a margin philosophy against the expected environment.*

R-12 *The expected environments and the required margin shall be documented.*

R-13 *The environments shall envelope what can be encountered during ground test, storage, transportation, launch, deployment, survival and normal operations from beginning of life to end-of-mission (EOM).*

4.1.2.2 Internal Environments

R-14 *Each project shall identify the internal environments for the mission, analyze and quantify the expected environment, and establish a margin philosophy against the expected environment.*

R-15 *Requirements derived from the mission environments shall be included in the Mission System Requirements.*

4.1.3 Operations Concept Development

The Operations Concept describes how the implemented mission is launched, deployed, commissioned, securely operated, and disposed of. An Operations Concept serves as a verification and validation reference for the design (see Figure 1). The operations concept describes how the design can accomplish the mission described by the objectives. Later in the design cycle the operations concept evolves into the mission or flight operations plan as shown in Table 1. An operations concept is necessary for the Identification and Management of Requirements (Section 4.1.4) and generating the Architecture and Design (Section 4.1.5).

R-16 *An Operations Concept shall be developed which addresses ground versus flight allocation of function.*

R-17 *The Operations Concept shall describe the various mission operational modes and configurations including Verification, Launch and Acquisition, In Orbit Checkout and Calibration (Commissioning), in addition to normal mission mode, and disposal if required.*

R-18 *The Operations Concept shall provide an overview of the Science objectives, the key measurements to be obtained, the Science regions of interest, any constraints for measurement taking.*

R-19 *The Operations Concept shall include a time ordered sequence of mission activities.*

This sequence forms the baseline for other engineering activities that need a mission timeline as an input.

R-20 *The Operations Concept shall identify facilities (to include all non-NASA supporting infrastructure elements), equipment, and procedures needed to ensure the safe development and operation of the system.*

R-21 *The Operations Concept shall describe functions that cut across various subsystems such as the Observation Strategy, Protection Strategy, Data Collection Storage and Downlink, Ground Station Utilization, Mission Orbit Maintenance and Maneuvers, Power and Battery Management.*

R-22 *The Operations Concept shall include a set of performance predictions that indicate requirements (Section 4.4) can be met given the architecture and design (Section 4.3).*

R-23 *The Operations Concept shall describe the operations team, size, staffing, and extent of automation.*

R-24 *The Operations Concept shall describe the ground segment functions, including data flow, primary interfaces, data processing algorithm development, level to which data will be processed, data archiving, data distribution, quantity of data with throughput and data latency.*

R-25 *The Operations Concept shall include Contingency Concepts that could include topics such as backup control centers, recovery from Loss of Communications, ACS Safing, and Load Shed.*

R-26 *The Operations Concept shall include ground test configurations necessary to accomplish verification (Sections 4 & 5) including Ground Support Equipment (GSE), Bench Test Equipment (BTE), Simulators and non-flight articles such as Engineering Test Units (ETUs).*

R-27 *The Operations Concept shall include operations to control hazards, maintain safety and protect space system assets.*

R-28 *The Operations Concept shall take into account coordination with other missions and operating agencies.*

R-29 *The outcome and decisions for key operations concept trade studies and optimizations shall be documented.*

Trade studies and analyses are used to demonstrate that the operations concept will meet the Mission Design Requirements including cost and schedule and are consistent with the architecture and design.

The Operations Concept is initially developed as a draft concept during Pre-phase A, with refinement throughout the life-cycle, until the flight operations plan is completed in Phase D.

R-30 *The Operations Concept shall be validated to the Mission System (Level 2) Requirements.*

Traceability should be established between the products to ensure consistency and that the validation activity has been performed.

4.1.4 Requirements Identification

Requirements communicate what functions a system must perform and how well it must perform them, i.e., functional and performance requirements. They also include the interface requirements and the set of "ilities" (reliability, availability, security, manufacturability, operability, maintainability, safety) the system must meet. The systems team should document the requirements appropriate to the complexity of the system element. Rationale should be documented for each requirement. Capturing the reasoning behind requirements is critical to future management of requirement changes.

R-31 *Requirements shall be organized into a hierarchy that flows down through the systems of interest.*

The levels of requirements are typically shown in a document tree. The mission level 1 requirements, usually defined in the project plan, define mission success criteria and serve as the top level for the requirements hierarchy.

R-32 *Requirements shall be organized into Functional and Performance categories.*

Functional Requirements describe what the system must do. Performance requirements are attached underneath their respective Functional Requirement. Performance requirements describe and document how well the function needs to be performed. Performance requirements are written in a verifiable manner.

R-33 *Specialty Engineering disciplines that apply across project elements shall be addressed in the requirements structure.*

These discipline areas levy requirements to multiple system elements. The discipline areas often include: Electrical Systems, Electromagnetic Interference & Electromagnetic Compatibility (EMI/EMC) and Grounding, Mechanical Systems, Thermal, Radiation Shielding, Parts Engineering, Contamination Engineering, Reliability Analysis, Charging, Timing and Time Distribution, Data Rate and Bandwidth Allocations, and susceptibility, vulnerability and survivability assessments.

4.1.5 Architecture and Design Development

The major goal of Systems Engineering is coordinating the engineering, design, and development of an Architecture and Design that meets the Requirements (Section 4.1.4), is consistent with the Operations Concept (Section 4.2), operates in the mission environment (Section 4.1.2), and can be developed on schedule and within cost. Block Diagrams are the key mechanism for documenting and communicating the architecture and design to the team.

R-34 *The Architecture and Design shall include the spacecraft, payload elements, ground systems, launch vehicle, communications segment and all non-NASA support infrastructure elements.*

R-35 *The Architecture and Design shall decompose the total system into its major parts to form the hierarchy (PBS) for lower level interfaces and specifications.*

The major parts of a system include the separate subsystems and boxes and their embedded hardware and software functions.

R-36 *The Architecture and Design shall include a logical decomposition and allocation of functions and performance to the PBS elements.*

R-37 *The Architecture and Design shall be analyzed, the analytical models maintained, and the analytical results used to establish an estimated performance baseline.*

R-38 *The Architecture and Design shall include any special test interfaces and test equipment necessary for verification, (Section 4.1.8).*

R-39 *The outcome and decisions of key architecture and design trade studies and optimizations shall be documented, (Section 4.2.7).*

R-40 *New technologies necessary for mission success shall be identified and potential risks identified and included in risk management, (Section 4.2.6).*

R-41 *The Architecture and Design shall identify hazards, single points of failure and safety/security requirements and implement necessary controls.*

The Architecture and Design are first generated in Pre-phase A and defined and refined until the end of Phase B, at the PDR. Initially the architecture should start out as functional or logical blocks. As the design matures the architecture should mirror the physical PBS. Once block diagrams and interfaces are defined then detailed design (Phase C) can proceed, without the risk of a major change induced by an architectural block diagram change.

R-42 *The Architecture and Design shall be validated to the Operations Concept and the Mission System (Level 2) Requirements.*

Traceability should be established between the products to ensure consistency and that the validation activity has been performed.

4.1.6 Product Implementation

Product implementation refers to the actual build process to generate the system of interest. During the implementation phase, the systems engineering team is responsible for ensuring that the system being fabricated adheres to the requirements, architecture, design, and other system specifications. During this phase, all of the Systems Management Functions (Section 4.2) play a major role in executing these expected activities.

4.1.7 Integration

An important element of systems engineering is the definition and planning of product integration. Integration planning includes the definition of acceptance criteria for the elements to be integrated. The assembly sequence, timing, and resources needed for integration are important to the overall success of the mission.

R-43 *Plans for the assembly and integration of product elements shall be developed and maintained.*

R-44 *Acceptance criteria shall be developed for all product elements.*

4.1.8 Verification

Verification includes those functions that make sure the team builds the system right, by verifying the design and implementation against the requirements. Tests and simulations function as the last line of defense against design and implementation defects that may compromise mission success. Verification is an important risk reduction function that attempts to uncover issues before they become problems on orbit.

R-45 *All identified requirements shall be verified.*

R-46 *Verification shall include identification of the verification item, the method (analysis, inspection, test or demonstration), and review and approval of the verification results.*

R-47 *Each project shall identify "What is not tested in flight configuration" and ascertain the risk associated with a non-flight like test configuration.*

The desire is to "test the way you fly it, and then fly it the way you test it" so that all functions are performed, and all environments are encountered, prior to launch. Where elements are tested in pieces or tested separately, attention to the interfaces and assumptions are critical to uncover hidden problems.

R-48 *Once the verification method is chosen, the responsible engineer shall verify the appropriate support equipment (GSE, BTE, and ETUs), tools, and facilities are available.*

By CDR, all of the requirements should be assigned a verification method.

R-49 *Test Planning documents shall be prepared that identify the environmental exposure as well as requirements for comprehensive, functional, aliveness, end-to-end, and mission simulation testing.*

Included are any other special or one-time tests necessary to verify hardware or software functionality. Special test equipment and test interfaces that are necessary for verification should be considered and documented along with the Architecture and Design, (Section 4.1.5).

Every effort should be made to perform a system end-to-end test, for example a telemetry end-to-end test scenario that provides stimulus input to the instruments, instrument processing, data flow through the spacecraft, transmitted to receiving antennas, and processing by the ground operations facility. This is the true test of the functionality of the system. Often such an end-to-end test cannot be fully achieved because of difficulties and expense in closing some of the links, or operating some of the flight segment in a one-g environment. In such cases, breaks in the chain are permitted, as long as the proper analysis and interface checks are performed to ensure the integrity of the overall end-to-end performance.

R-50 *Non-conformances identified during requirements verification shall be documented and dispositioned, consistent with GPR 5340.2, using either a problem reporting system or a configuration management system such as Configuration Change Requests or Waivers.*

R-51 *Environments identified under Section 4.1.2, Mission Environments, shall be verified according to test guidelines established by the General Environmental Verification Specification - GSFC-STD-7000.*

R-52 *Performance measurements and test results shall be used to update the expected performance model in order to assess the margin between required and expected performance.*

During Phase D, verification results are compared against the requirements to track conformance and compliance. Most requirements should be verified by the Pre-Ship Review and all by the Flight Readiness Review.

R-53 *The systems engineer shall assign responsibility for reviewing and approving the results of verification activities.*

The review of verification results is particularly effective in identifying and correcting problems. Verification status reporting is used to track conformity, performance, and completeness.

R-54 *Verification status and results shall be tracked back to the requirements using a method or tool chosen by the project.*

R-55 *Verification shall include the effort necessary to make sure the end item performs as intended by design. End-to-end testing and mission simulations are the intended methods.*

R-56 *The Verification Program shall be validated to assure that all requirements are verified, and that the system operates as required by the Operations Concept.*

Verification shall include the effort necessary to show redundant or backup functions operate as intended, to enable fault recovery or graceful degradation modes.

This verification includes verifying that procedures or onboard fault protection features actually protect the system, should faults occur.

Verification includes making sure the end item, and its support or ground equipment, functions in the intended operational scenario. When verifications are performed by analysis, the analytical models must be validated for correctness and the required fidelity as referenced in NASA-STD-7009. Detailed design features that are developed in the design process must also be verified. Verifying Mission Design Requirements alone is generally not sufficient for launch readiness.

The GSE and BTE, facilities, plans and procedures shall be validated to the verification methods.

4.1.9 Validation

Validation is used to assure that the mission design will meet the mission objectives. It is a continuing process that encompasses the validation of the Operations Concept, the Architecture and Design, the Requirements, the mutual consistency of these three elements, and the verification program.

The Operations concept is validated to the Mission Validation Basis. This validation assures that the operational design will operate the spacecraft and instruments in a way that will achieve the Mission Objectives.

R-57 *The Operations Concept shall be validated to assure that the operation of the system will meet Mission Objectives by achieving the Measurement Concept and accommodating the Payload Concept.*

The Requirements are validated to the Mission Validation Basis. This assures that all of the functions needed to meet objectives are defined and that the required performance of each function is captured.

During the design phases, performance predictions, trade studies and analyses are used to validate that the chosen design meets the requirements, when utilized according to the Operations Concept.

Validation also establishes requirements tracing to ensure that the higher-level requirements flow to a lower level or child requirement. Requirements validation also makes sure that the lower level requirements have a parent requirement. Orphan requirements, ones without a higher-level parent, are evaluated to determine if they are needed.

R-58 *Requirements shall be validated to assure that the system will meet the Mission Objectives, be capable of performing the Measurement Concept, accommodate the Payload Concept, and operate as defined in the Operations Concept.*

R-59 *Each project shall decide on the mechanism for tracking the requirements and who is responsible for the requirements flow and verification.*

The Architecture and Design is validated to the Mission Validation Basis. This assures that the design will accommodate the instruments, implement the required functions, and achieve the performance needed to meet Mission Objectives.

R-60 *The Architecture and Design shall be validated to assure that the operation of the system will meet Mission Objectives by implementing the functions and achieving the performance needed to achieve the Measurement Concept and accommodate the Payload Concept.*

The Operations Concept, Architecture and Design, and Requirements are validated to assure mutual consistency. Each of these elements affects the others. The Operations Concept determines the partitioning of function among the space element, the ground element, and the launch element. It defines modes of operation and timing which drive both the requirements and design. The requirements capture the functionality and performance the design must achieve. This includes operationally driven requirements. The design must be able to operate according to the Operations Concept and must implement the requirements. This mutual dependency is strongly coupled, thus mutual consistency must be validated.

R-61 *The Operations Concept, Requirements, and Architecture and Design shall be validated to assure mutual consistency.*

The verification methods (inspection, analysis, test and demonstration), facilities, GSE and BTE, test levels, and test activities together define a verification program which defines how the system will be verified. The verification program is validated to the requirements to assure that every requirement is verified. Validation of the verification program to the Operations Concept assures that the system will operate as required.

Phase A and Phase B validation activities strive to show that the right system design has been chosen before detailed design proceeds in Phase C. Validation that the requirements are consistent with the design and operations concept, early in the life-cycle, minimizes the chance that the wrong system is designed. Phase C and D verification activities show that the chosen system design is implemented correctly. Validation also occurs later in the life cycle when mission simulations, end-to-end tests, and other activities show that the system design correctly meets the customer's intent

4.1.10 Acceptance and Transition

The systems engineering teams participate in the transitioning of end products to the next higher level PBS-model customer and, eventually, to the end user. As end products are fabricated, and end product documentation is generated, they proceed through a cycle of product verification (section 4.1.7), product validation (section 4.1.8) and product transition to the next higher PBS level in Phase D (System Assembly, Integration, Test, and Launch) of the project life-cycle. Product Integration takes place at this next higher PBS level and this cycle continues until final assembly verification and validation occurs and the system is fully integrated and transitions to the end user in Phase E (Operations and Sustainment).

R-62 *Acceptance criteria shall be developed for system end products.*

R-63 *The systems engineering team shall plan for the availability of products, people and facilities to support product integration at all PBS levels leading to the top level of the PBS prior to transition to the end user.*

R-64 *Plans for the transition of end products to the next higher PBS level shall be developed, reviewed and maintained.*

R-65 *The systems engineering team shall plan for the availability of products, people, and facilities for product transition.*

R-66 *The systems engineering team shall validate that the technical data packages and other end product documentation meet Mission Design Requirements.*

4.2 Systems Management Functions

This section addresses the system management functions that should be applied during the entire lifecycle of the project/program as ongoing systems engineering activities. It is expected that these will be employed to varying degrees dependent upon the class of mission and size of project/system of interest being developed. In many cases, projects and programs will share processes and utilize a common set of processes or either delegate a process down to a project level or elevate a process to encompass the entire program. In any event, the systems engineering teams must determine the best approach, document in each SEMP (project/program/subsystem – if applicable) all of the below management functions as to the allocation and who is leading the activity.

4.2.1 Requirements Management

R-67 *The Requirements flow hierarchy shall be consistent with the Product Breakdown Structure. Requirements are decomposed and allocated to products down through the PBS. Ideally, this continues until a single engineer is responsible for the product. Some shared requirements may flow between and across subsystem elements.*

R-68 *Shared requirements shall be documented either within the requirements tree, or in a separate specification such as Electro-Magnetic Interference (EMI), Environmental, Electrical Systems, Contamination, etc., or as part of Resource Budgets.*

R-69 *Shared requirements shall be referenced by all elements to which they apply. By the end of Phase C, and the CDR, the requirements flow, down to build-to specifications, should be complete.*

R-70 *The outcome and decisions for key requirements trade studies and optimizations shall be documented, (Section 5).*

Trade studies and analysis are used to refine the requirements along with the Operations Concept and the Architecture and Design to meet the Mission Design Requirements including cost and schedule.

4.2.2 Interface Management

Interface Management allows the system boundaries and conditions to be defined and managed during the project lifecycle. There are 3 different mechanisms used to document the interfaces for a different system:

1. Interface Description Document – this mechanism is used to document an interface in a unilateral fashion to record assumptions made based on interface information available.

2. Interface Requirement Document – this is used to record the requirements for a particular system interface and typically is generated early in the project lifecycle to document agreements on a bilateral basis.
3. Interface Control Document – this is used to document the functional, physical, thermal, data protocol, etc., level as the architecture/design/development progresses during the project lifecycle to maintain agreements on a bilateral basis.

ICDs describe where and how various system elements need to connect or communicate with each other and also where isolation is required to prevent interference or undesired interaction. Interfaces and ICDs, between elements of the block diagram, describe the topologies of the interfaces. Defined interfaces allow multiple detailed designs to proceed in parallel. Defining interfaces is an important outgrowth of requirements allocation. Once requirements and functions have been partitioned, the interfaces can be defined.

R-71 *Requirements shall specify the interfaces or reference configured interface specifications.*

R-72 *A list of all interfaces requiring an ICD shall be documented and maintained.*

R-73 *The project team shall decide which ICDs are necessary, given the complexity, organization structure, and participants.*

Interface requirements should be well defined before PDR, to allow detailed design to proceed with minimal risk of changes.

R-74 *The ICDs shall be validated to the Architecture and Design and the Requirements.*

4.2.3 Technical Planning

The technical planning process is used to plan for the application and management of each key systems engineering function and to identify, define, and plan the technical effort applicable to the product-line life-cycle phase for PBS model location within the system structure and to meet project objectives and product-line life-cycle phase exit criteria. A key document generated by this process is the SEMP of which the primary function is to provide the basis for implementing the technical effort and communicating what will be done, by whom, when, where, cost drivers, and why it is being done. In addition, the SEMP identifies the roles and responsibility interfaces of the technical effort and how those interfaces will be managed.

R-75 *The Product Manager and the Lead Systems Engineer shall prepare a SEMP that addresses the requirements of this GPR and describes What, When, Where, by Whom, and How each are to be implemented.*

R-76 *Working with the program/project manager, the technical team shall determine the appropriate level within the system structure at which SEMPs are developed, taking into account factors such as number and complexity of interfaces, operating environments, and risk factors.*

Lower level plans will be consistent with the project SEMP.

R-77 *The SEMP shall include an organization structure along with responsibilities for the Systems Engineering Team.*

R-78 *The SEMP shall include major trade studies, which should be identified when the SEMP is baselined during life cycle Phase A and changes captured during subsequent system milestone reviews.*

R-79 *The SEMP shall include a schedule and list of resources required for the systems engineering effort.*

R-80 *Discipline technical plans shall be validated to the SEMP for consistency.*

Discipline technical plans include subsystem technical plans such as subsystem implementation plans.

R-81 *Software Development and Management Plans shall be validated to the SEMP for consistency.*

Appendix D contains the annotated SEMP outline. The project SEMP is generated during Pre-Phase A and the SEMP is baselined in Phase A. The SEMP should be updated as necessary when major changes occur. The details of schedule, workflow, and the order of activities should be continuously updated as part of ongoing planning. The DGA will review and approve or disapprove the SEMP at each major milestone review or its equivalent.

4.2.4 Technical Resource Budget Tracking

R-82 *Each project shall identify the mission resources to be allocated and tracked.*

R-83 *Each project shall define acceptable resource margins and then set up a margin management philosophy based on design maturity and time.*

The margin philosophy includes a process for reducing required margin throughout the project's life. For example, at PDR a 30% margin may be appropriate, with reductions to 10% at CDR and 3%, or lower, close to flight. Another factor in margin tracking is the precision of the estimate. Estimated, calculated and measured numbers can carry different uncertainties and may require different margins. Reference GSFC-STD-1000 for recommended guidelines for items such as margins per development phase.

Resource budgets may include, Mass, Power, Battery, Fuel, Memory, Processor Usage, Data Rate and Volume, Telemetry, Commands, Data Storage, RF Link, Contamination, Alignment, Total Dose Radiation, SEE, Surface and Internal Charging, Meteoroid, Atmospheric (atomic oxygen), ACS Pointing and Disturbance (Atmospheric Drag, Gravity Gradient, Solar Pressure), and RF exposure on the ground and on orbit.

Care must be taken to ensure that additional reserves are not added to margins. The lead systems engineer holds the overall system margins. Some margins may be allocated to subsystems engineers in order to meet their design requirements. This hierarchy of margins must be taken into account so that the overall system margins do not unnecessarily drive the design and the cost.

4.2.5 Configuration Management and Data Storage

The project's configuration management system functions as a library for documentation control, access, and dissemination. Documents are placed into the library to serve as a single, configured, point-of-reference for the project team. The guidelines for the configuration management system are contained within GPR 1410.2, Configuration Management.

R-84 *Each project shall choose the Systems Engineering documents necessary for inclusion in its Configuration Management Office, and the degree of formality assigned to document change control.*

Each project establishes a mechanism to disseminate the latest information and to archive the results of System Trade Studies, Reports and Analysis.

R-85 *Documents stored in the library shall include the configured, single point of reference for the Operations Concept, Architecture and Design, Requirements, Technical Data and Resource Budgets, Mission Environments, and the Systems Engineering Management Plan (SEMP).*

The project decides what is necessary for future reference, or in support of the review process, documenting what was done, or why it was done. Documents can be placed under formal configuration management or stored in an information system for access. A process for the identification and use of latest revisions is required, in accordance with GPR 1410.2.

The Systems Engineer participates in the establishment of the Configuration Control Board (CCB) and is assigned to the CCB.

R-86 *The systems engineer shall generate a document tree that shows the requirements hierarchy.*

Other documents, such as the In-Orbit Checkout Report and the End of Mission and Disposal Report, should be considered for configuration management.

R-87 *The technical team shall define an approach to manage project technical data, including technical data obtained from any contracted technical effort.*

The technical data management task includes identifying and controlling data requirements, collecting and disseminating technical data throughout the product life-cycle, assessing and updating data and providing for technical data record keeping. For example, technical data should be stored using a common data format with the users of the data.

4.2.6 Risk Management

Risk management is an organized, systematic decision-making process that efficiently identifies, analyzes, plans (for the handling of risks), tracks, controls, communicates, and documents risks to increase the likelihood of achieving mission goals. NPR 8000.4, Risk Management Procedural Requirements, and NPR 8705.5, Probabilistic Risk Assessment (PRA) Procedures for NASA Programs and Projects provide overall guidance, while GPR 7120.4, Risk Management, provides procedures and guidelines for applying risk management to GSFC projects.

The senior managers of the project team, particularly the Project Manager, Lead Systems Engineer and Chief Safety and Mission Assurance Officer (CSO) are expected to personally and actively lead the risk management decision-making process. The Lead Systems Engineer and the systems engineering team perform a particularly vital role in the identification, analysis, planning, tracking, controlling, communicating and documenting of risks relative to achieving the success criteria.

The contributions of the systems engineering team are crucial to the discussion of the acceptable risk level for the mission and the development of a reliability philosophy commensurate with the agreement on acceptable risk. The acceptable risk and reliability philosophy shape the mission assurance requirements necessary to achieve mission success. The reliability philosophy encompasses everything that is done to assure a reliable system (e.g., parts selection and screening, analysis and simulations, test program, reviews, contingency planning) and what reliability analyses are planned to look for problems and investigate what could go wrong.

Paragraphs 2.5 through 2.8 of GPR 7120.4 provide risk management requirements particularly applicable to the responsibilities of the Lead Systems Engineer:

R-88 *A Failure Modes and Effects Analysis (FMEA) shall be performed early in the design phase to identify system design problems (flight and ground, hardware and software).*

Refer to paragraph 2.5 of GPR 7120.4.

R-89 *Fault Tree Analyses (FTA) shall be performed to address both mission failures and degraded modes of operation.*

Refer to paragraph 2.6 of GPR 7120.4.

Comparative numerical reliability assessments and/or reliability predictions, such as Probabilistic Risk Assessment (PRA), should be used to evaluate and optimize the system. This includes:

Evaluate alternative design concepts, redundancy and cross-strapping approaches, and part substitutions;

(1) Identify the elements of the design that are the greatest detractors of system reliability;

(2) Identify those potential mission limiting elements and components that will require special attention in part selection, testing, environmental isolation, and/or special operations;

(3) Assist in evaluating the ability of the design to achieve the mission life requirement and other reliability goals and requirements as applicable; and

(4) Evaluate the impact of proposed engineering change and waiver requests on reliability.

R-90 *The Risk Management Plan shall document the project's decision on utilizing PRA and similar techniques in the project systems engineering process.*

Refer to paragraph 2.7 of GPR 7120.4

R-91 *The results of FMEA's, FTA's and any numerical reliability assessments or predictions shall be reported at system-level critical milestone reviews.*

Refer to paragraph 2.8 of GPR 7120.4. The first FTA is appropriate during Phase A. Reliability analyses and results should be presented in preliminary form at PDR, with updates at CDR, and final products consistent with the as-built configuration.

4.2.7 Decision Analysis

Many of the key systems engineering functions require technical decisions based on the evaluation of technical alternatives. Decisions from key operations concept trade studies are used to demonstrate that the operations concept will meet the mission design requirements and is consistent with the architecture and design (see 4.1.1). Conversely, decisions from key requirements trade studies and analyses are used to refine the requirements along with the operations concept and the architecture and design to meet the mission design requirements (see 4.1.2). Also, concept development includes trades and decisions (see 4.2.7) and risk management is seen as an organized, systematic decision-making process (see 4.2.8).

R-92 *The methodology to be employed for identifying, performing and documenting trade studies to be conducted shall be identified in the SEMP.*

The SEMP should indicate what methods are available, permissible and under which conditions a particular method should or could be used. This will allow the SEMP to provide criteria for different levels of trades to be performed corresponding with identified technical risks, schedule and cost impacts, and for the SE team to collaborate with trade study participants as to the methods to be employed on any potential trade to be performed.

R-93 *The Technical team shall identify, track, document the results of key trade studies and integrate the results into mission products.*

In key technical decisions the mission team should consult Section 6.8.2 of the NASA Systems Engineering Handbook (SP-6105), Revision 1.

4.2.8 Acquisition Support

Mission acquisition support begins early in the mission life-cycle. During Pre-phase-A concept development or proposal development, Requests For Information (RFI), and Requests for Proposals (RFP) are often developed, either to understand concept solutions, or to establish partnership or teaming arrangements for a particular mission. Early make or buy decision have a strong effect on the overall effort.

Both RFI and RFP documents require the development of SOWs that define the scope and requirements for the products and work being sought. Contractual requirements for the offerer's SEMP, work products, technical oversight, and reviews must be included for the team to function successfully.

Participation in the evaluation of offerer proposals for source selection is essential by the systems engineering team to ensure that proper visibility and authority is in place to enable the technical oversight of the contract, and that offerer plans and work products meet mission needs.

Once contracts are in place, it is important that the technical oversight be executed, reviews conducted, and product acceptance evaluated to maximize mission success.

R-94 *Concept development shall include make or buy trades and decisions to optimize mission performance and cost*

R-95 *Statements of Work (SOW) shall be developed.*

R-96 *The SOW shall include the definition of the offerer's SEMP and other work products.*

R-97 *The SOW shall include technical oversight requirements*

R-98 *The SOW shall include support activities for product transition and disposal as appropriate.*

R-99 *A contractor surveillance plan shall be developed to address how the technical effort will be monitored, tracked and reported by the oversight organization.*

R-100 *Technical evaluation of offerer's proposals shall be performed.*

R-101 *Technical oversight and reviews, as defined in the SOW, shall be performed.*

5 SYSTEMS ENGINEERING REVIEWS AND DELIVERABLES

Reviews are held to assess the progress of the technical effort and to validate the quality and completeness of a systems engineering phase or portion thereof. Reviews are a tool for communication within the team. The preparatory integration and structured presentation of requirements, design information, analyses, engineering products, test and operations plans, etc., facilitates knowledge sharing and identification and resolution of challenges and issues. Reviews are a source of validation, ideas, best practices and lessons learned from experts outside of the project team.

The system milestone reviews for robotic mission projects are listed in Table 2. The description of the reviews can be found in GSFC-STD-1001.

R-102 *The monitoring function for traditional FS&GS projects shall be accomplished using the following required minimum set of technical reviews: Mission Concept Review (MCR), System Requirements Review (SRR), System Definition Review (SDR) and/or Mission Definition Review (MDR), Preliminary Design Review (PDR), Critical Design Review (CDR), Systems Integration Review (SIR), Test Readiness Review (TRR), System Acceptance Review (SAR)/Element Pre-Ship Review (PSR), Observatory Pre-Ship Review (PSR), Operational Readiness Review (ORR) and/or Mission Readiness Review (MRR), Flight Readiness Review (FRR), Operational Acceptance Review (OAR), Post-Launch Assessment Review (PLAR) and Decommissioning Review (DR).*

R-103 *In addition, the minimum set of mission reviews shall include GSFC-specific technical reviews such as the Mission Operations Review (MOR), Pre-Environmental Review (PER), Flight Operations Review (FOR), Launch Readiness Review (LRR), Critical Event Readiness Review (CERR), Safety and Mission Success Review (SMSR), and Mission Readiness Brief (MRB)/MRR that will be employed by the robotic mission projects as shown in Figures 2, 3 and 4 and Table 1 (Key Function 4.10 & Note 3).*

Reviews at the program level and reviews for human mission projects are slightly different. The description of these reviews can be found in NPR 7120.5 and NPR 7123.1.

Figures 2 through 4 align the reviews with respect to the life-cycle phase in which they are conducted. The progress between life-cycle phases is marked by key decision points (KDPs). Figures 2 and 3 show KDP C as the point of project acceptance or confirmation, allowing for transition from Formulation to Implementation.

R-104 *Engineering Peer Reviews, including systems engineering peer reviews, shall be planned and conducted in accordance with GPR 8700.6.*

R-105 *Integrated Independent Reviews shall be planned and conducted in accordance with GPR 8700.4 and GSFC-STD-1001. Required IIRs include the GSFC-specific mission reviews and the reviews conducted on defined mission elements and systems (such as spacecraft, instruments and ground systems).*

R-106 *For all reviews documented in the SEMP, the technical team shall address the entrance and success criteria listed in GSFC-STD-1001 and in Appendix G of NPR 7123.1 for applicability to the respective reviews.*

Table 2 in Section 1 of this document shows a list of typical systems documents that meets NPR 7123.1 documentation requirements. NPR 7123.1 addresses the requirements for each review and includes the set of deliverables for each milestone review.

Appendix A - Definitions

Architecture and Design – A description of the mission elements, their interfaces, their logical and physical layout, and the analysis of the design to determine expected performance and margins. Includes System Design Synthesis, System Design Analysis, and System Design Validation products.

Configuration Management – A systematic process for establishing and maintaining control and evaluation of all changes to baseline documentation, products (Configuration Items), and subsequent changes to that documentation, which defines the original scope of effort. The systematic control, identification, status accounting, and verification of all Configuration Items throughout their life cycle.

Designated Governing Authority – The management entity above the program, project, or activity level with technical oversight responsibility.

Development Risk – Risk of not delivering a quality product on time and within cost.

Interface Control Document (ICD) – A specification of the mechanical, thermal, electrical, power, command, data, and other interfaces that system elements must meet.

Key Decision Point (KDP) – The event at which it is determined that the program or project is ready to progress to the next phase of the life cycle (or to the next KDP).

Lead Subsystems Engineer – The engineer responsible for the overall development and implementation of the subsystem products. This person may also serve as the Product Manager or Product Design Lead.

Lead Systems Engineer – The systems engineer, also often referred to as the Mission Systems Engineer (MSE) or Instrument Systems Engineer (ISE), responsible for leading and integrating the efforts of the systems engineering team and the overall development and implementation of the mission, project, or instrument design.

Level 1 Requirement – A Project's fundamental and basic set of requirements levied by the Program or Headquarters on the project.

Measurement Concept – A concept that defines what measurements must be taken to achieve the Science Objectives. Includes characteristics of measurements, such as, spectral band, resolution, sample rate, duration of observation, type of observation, vantage, and others. This includes New Technology Validation Concepts.

Mission Design Requirements – The high-level requirements needed to achieve the science measurements. These include launch date, mission duration, orbit, and other strategic requirements which drive the Mission Architecture.

Mission Needs – There are four elements of mission needs: (1) mission objectives which capture the science objectives; (2) programmatic objectives that define the overall goals and constraints of the mission; (3) measurement concept that defines the science measurements needed to achieve the science objectives; and (4) payload concept that defines the instrument characteristics, function and performance needed to make the measurements.

Mission Systems Engineer – See Lead Systems Engineer

Mission System Requirements – (Architectural) The high-level requirements that describe the major segments that comprise the system architecture and the key elements of each segment. For GFSC missions, a typical architecture consists of launch segment, space segment, ground segment, and science data processing segment.

Objectives – A set of goals and constraints that define the purpose of the mission and the programmatic boundaries, and provide a basis for the Level I requirements and mission success criteria. Usually captured as Science Objectives and New Technology Validation Objectives.

On Orbit Mission Success Risk – Risk of not meeting on orbit mission success criteria.

Operations Concept – A concept that defines how the mission will be verified, launched, commissioned, operated, and disposed of. Defines how the design is used to meet the requirements.

Payload Concept – A concept that defines the characteristics of the instruments needed to execute the measurement concept.

Product Breakdown Structure (PBS) – A hierarchical tree that shows the composition of the system, sub-systems, assemblies, components, and other mission products (see Section 4.3). The PBS is used to ensure that all elements are accounted for in the design and development activities.

Project Life cycle – The incremental pieces that NASA space flight projects are divided into that allow managers to assess management and technical progress. These phases are defined as: Formulation, Approval, and Implementation.

Requirement – A statement of a function to be performed, a performance level to be achieved, or an interface to be met. Requirements are indicated by the word “shall”.

Requirements Document – An organized hierarchy of requirements that provides a *validation basis* for a system or system element.

Risk Analysis – The activity of identifying risks, and the analysis of the probability of occurrence and the consequence of occurrence.

Risk Reduction – The activities performed to reduce the likelihood of a risk occurring, the consequence should the risk occur, or both.

Resource Tracking – The activity of tracking and maintaining technical resource allocations, estimates, and margins for system elements. Technical resources include, mass, power, volume, area, pointing accuracy and knowledge, link margin, and others.

Safety Risk – Risk of injury to personnel, facilities or hardware.

Space Environment & Specialty Engineering – Engineering to analyze the mission space environment and establish the design, implementation, and verification policies and requirements appropriate to the environment.

Specification – A document that prescribes, in a complete, precise, verifiable manner, the requirements, design, behavior, or characteristics of a system or system element. A specification provides a *verification basis* for a system or system element.

System of Interest – The identified part of the system hierarchy, whether a part, assembly, or subsystem, that is assigned to the engineering team.

Systems Engineering Life-Cycle – Concept Studies (Pre-Phase A), Preliminary Analysis (Phase A), Definition (Phase B), Design (Phase C), Development (Phase D), Mission Operations (Phase E) and Disposal (Phase F) are the systems engineering life-cycle phases. Development includes Acquisition, Fabrication, and Integration; Verification and Preparation for Deployment; and Deployment and Operations Verification.

Systems Engineering Management Plan (SEMP) – An implementation plan for the performance of systems engineering functions and the development of systems engineering products. This plan identifies what, when, where, by whom, and how the functions are performed. It specifies the schedule for the development, and the resources required.

Technical Authority – The key individual accountable and responsible for the technical integrity of a flight mission.

Validation – Proof that the Operations Concept, Requirements, and Architecture and Design will meet Mission Objectives, that they are mutually consistent, and that the "right system" has been designed. May be determined by a combination of test, demonstration or analysis. Generally accomplished through trade studies and performance analysis by Phase B and through tests in Phase D.

Validation Basis – A set of requirements that provides the success criteria for a system or system element.

Verification – Proof of compliance with requirements and that the system has been "Designed and Built Right." May be determined by a combination of test, analysis, demonstration and inspection.

Verification Basis – A set of specifications that define details of implementation, function, and performance to be verified.

Appendix B - Acronyms

ACS – Attitude Control System
AETD – Applied Engineering and Technology Directorate
ATD – Advanced Technology Development
BAR – Basic and Applied Research
BTE – Bench Test Equipment
CCB – Configuration Control Board
CDR – Critical Design Review
CERR – Critical Event Readiness Review
CM – Configuration Management
CSO – Chief Safety and Mission Assurance Officer
DGA – Designated Governing Authority
DR – Disposal Review or Decommissioning Review
EMC – Electromagnetic Compatibility
EMI – Electromagnetic Interference
EOM – End of Mission
ETU – Engineering Test Units
FMEA – Failure Modes and Effects Analysis
FOR – Flight Operations Review
FRR – Flight Readiness Review
FS&GS – Flight Systems and Ground Support
FTA – Fault Tree Analysis
GEVS – General Environmental Verification Specification
GPR – Goddard Procedural Requirements
GSFC – Goddard Space Flight Center
GSE – Ground Support Equipment
ICD – Interface Control Document/Drawing
IIR – Independent Integrated Review
IP – Institutional Projects
ISE – Instrument Systems Engineer
IT – Information Technology
KDP – Key Decision Point
LSE – Lead Systems Engineer
MCR—Mission Concept Review
MDR – Mission Definition Review
MOR – Mission Operations Review
MRB – Mission Readiness Brief
MRR – Mission Readiness Review
MSE – Mission Systems Engineer
NPR – NASA Procedural Requirements
ODA – Orbital Debris Analysis

ORR – Operations Readiness Review
PBS – Product Breakdown Structure
PDR – Preliminary Design Review
PER – Pre-Environmental Review
PLAR – Post Launch Assessment Review
PRA – Probabilistic Risk Assessment
PSR – Pre-Ship Review
RF – Radio Frequency
RFI – Request for Information
RFP – Request for Proposals
SAR – System Acceptance Review
SCR – System Concept Review
SDR – Systems Definition Review
SEE – Single Event Effects
SEMP – Systems Engineering Management Plan
SIR – System Integration Review
SMSR – Safety and Mission Success Review
SOW – Statement of Work
SRR – System Requirements Review
TRR – Test Readiness Review
WBS – Work Breakdown Structure

Appendix C - Systems Engineering Requirements

Reqt #	Requirement
R-1	This GPR shall be applied to all GSFC managed Flight Systems & Ground Support (FS&GS) projects that are required to follow NPR 7120.5, NASA Space Flight Program and Project Management.
R-2	Projects specifically excluded from the application of this GPR are Basic and Applied Research (BAR), Advanced Technology Development (ATD), Institutional Projects (IP), and Institutional IT Projects.
R-3	For systems that contain software, the mission team shall ensure that software acquired or developed internally within NASA complies with NPD 2820.1, NASA Software Policy, and NPR 7150.2, NASA Software Engineering Requirements.
R-4	For programs and projects involving more than one Center, the lead organization shall develop documentation to describe the hierarchy and reconciliation of center plans implementing NPR 7123.1.
R-5	The Product Manager for the systems development function, typically a Study Manager, Project Formulation Manager, Project Manager, or Instrument Manager, shall work with the DGA to select a Lead Systems Engineer.
R-6	The Product Manager and the Lead Systems Engineer shall develop the plan for the systems engineering effort and establish a systems engineering team along with roles and responsibilities.
R-7	The Designated Governing Authority (DGA) or his/her designate shall have responsibility to approve or disapprove any requirement of this document that is either tailored or waived.
R-8	The results of Technical Planning, including the associated roles and responsibilities, are captured in the SEMP (Section 4.2.3).
R-9	The technical team shall baseline the SEMP prior to the completion of Phase A and update at each major milestone review or its equivalent. The DGA or designate shall review and approve or disapprove the SEMP at each major milestone review or its equivalent.
R-10	Each Project shall work with the stakeholders and the appropriate Enterprise Office at NASA Headquarters to prepare a set of Mission (Level 1) Requirements that form the validation basis for the Mission System (Level 2) Requirements.
R-11	Each project shall identify the external environments for the mission, analyze and quantify the expected environment, establish design guidance, and establish a margin philosophy against the expected environment.
R-12	The expected environments and the required margin shall be documented.
R-13	The environments shall envelope what can be encountered during ground test, storage, transportation, launch, deployment, survival and normal operations from beginning of life to end-of-mission (EOM).

Reqt #	Requirement
R-14	Each project shall identify the internal environments for the mission, analyze and quantify the expected environment, and establish a margin philosophy against the expected environment.
R-15	Requirements derived from the mission environments shall be included in the Mission System Requirements.
R-16	An Operations Concept shall be developed which addresses ground versus flight allocation of function.
R-17	The Operations Concept shall describe the various mission operational modes and configurations including Verification, Launch and Acquisition, In Orbit Checkout and Calibration (Commissioning), in addition to normal mission mode, and disposal if required.
R-18	The Operations Concept shall provide an overview of the Science objectives, the key measurements to be obtained, the Science regions of interest, any constraints for measurement taking.
R-19	The Operations Concept shall include a time ordered sequence of mission activities.
R-20	The Operations Concept shall identify facilities (to include all non-NASA supporting infrastructure elements), equipment, and procedures needed to ensure the safe development and operation of the system.
R-21	The Operations Concept shall describe functions that cut across various subsystems such as the Observation Strategy, Protection Strategy, Data Collection Storage and Downlink, Ground Station Utilization, Mission Orbit Maintenance and Maneuvers, Power and Battery Management.
R-22	The Operations Concept shall include a set of performance predictions that indicate requirements (Section 4.4) can be met given the architecture and design (Section 4.3).
R-23	The Operations Concept shall describe the operations team, size, staffing, and extent of automation.
R-24	The Operations Concept shall describe the ground segment functions, including data flow, primary interfaces, data processing algorithm development, level to which data will be processed, data archiving, data distribution, quantity of data with throughput and data latency.
R-25	The Operations Concept shall include Contingency Concepts that could include topics such as backup control centers, recovery from Loss of Communications, Attitude Control System (ACS) Safing, and Load Shed.
R-26	The Operations Concept shall include ground test configurations necessary to accomplish verification (Sections 4 & 5) including Ground Support Equipment (GSE), Bench Test Equipment (BTE), Simulators and non-flight articles such as Engineering Test Units (ETUs).
R-27	The Operations Concept shall include operations to control hazards, maintain safety and protect space system assets.
R-28	The Operations Concept shall take into account coordination with other missions and operating agencies.

Reqt #	Requirement
R-29	The outcome and decisions for key operations concept trade studies and optimizations shall be documented.
R-30	The Operations Concept shall be validated to the Mission System (Level 2) Requirements.
R-31	Requirements shall be organized into a hierarchy that flows down through the systems of interest.
R-32	Requirements shall be organized into Functional and Performance categories.
R-33	Specialty Engineering disciplines that apply across project elements shall be addressed in the requirements structure.
R-34	The Architecture and Design shall include the spacecraft, payload elements, ground systems, launch vehicle, communications segment and all non-NASA support infrastructure elements.
R-35	The Architecture and Design shall decompose the total system into its major parts to form the hierarchy (PBS) for lower level interfaces and specifications.
R-36	The Architecture and Design shall include a logical decomposition and allocation of functions and performance to the PBS elements.
R-37	The Architecture and Design shall be analyzed, the analytical models maintained, and the analytical results used to establish an estimated performance baseline.
R-38	The Architecture and Design shall include any special test interfaces and test equipment necessary for verification. (Section 4.1.8)
R-39	The outcome and decisions of key architecture and design trade studies and optimizations shall be documented. (Section 4.2.7)
R-40	New technologies necessary for mission success shall be identified and potential risks identified and included in risk management, (Section 4.2.6).
R-41	The Architecture and Design shall identify hazards, single points of failure and safety/security requirements and implement necessary controls.
R-42	The Architecture and Design shall be validated to the Operations Concept and the Mission System (Level 2) Requirements.
R-43	Plans for the assembly and integration of product elements shall be developed and maintained.
R-44	Acceptance criteria shall be developed for all product elements.
R-45	All identified requirements shall be verified.
R-46	Verification shall include identification of the verification item, the method (analysis, inspection, test or demonstration), and review and approval of the verification results.
R-47	Each project shall identify "What is not tested in flight configuration" and ascertain the risk associated with a non-flight like test configuration.

Reqt #	Requirement
R-48	Once the verification method is chosen, the responsible engineer shall verify the appropriate support equipment (GSE, BTE, and ETUs), tools, and facilities are available.
R-49	Test Planning documents shall be prepared that identify the environmental exposure as well as requirements for comprehensive, functional, aliveness, end-to-end, and mission simulation testing.
R-50	Non-conformances identified during requirements verification shall be documented and dispositioned, consistent with GPR 5340.2, using either a problem reporting system or a configuration management system such as Configuration Change Requests or Waivers.
R-51	Environments identified under Section 4.1.2, Mission Environments, shall be verified according to test guidelines established by the General Environmental Verification Specification - GSFC-STD-7000.
R-52	Performance measurements and test results shall be used to update the expected performance model in order to assess the margin between required and expected performance.
R-53	The systems engineer shall assign responsibility for reviewing and approving the results of verification activities.
R-54	Verification status and results shall be tracked back to the requirements using a method or tool chosen by the project.
R-55	Verification shall include the effort necessary to make sure the end item performs as intended by design. End-to-end testing and mission simulations are the intended methods.
R-56	The Verification Program shall be validated to assure that all requirements are verified, and that the system operates as required by the Operations Concept.
R-57	The Operations Concept shall be validated to assure that the operation of the system will meet Mission Objectives by achieving the Measurement Concept and accommodating the Payload Concept. The Requirements are validated to the Mission Validation Basis.
R-58	Requirements shall be validated to assure that the system will meet the Mission Objectives, be capable of performing the Measurement Concept, accommodate the Payload Concept, and operate as defined in the Operations Concept.
R-59	Each project shall decide on the mechanism for tracking the requirements and who is responsible for the requirements flow and verification.
R-60	The Architecture and Design shall be validated to assure that the operation of the system will meet Mission Objectives by implementing the functions and achieving the performance needed to achieve the Measurement Concept and accommodate the Payload Concept.

Reqt #	Requirement
R-61	The Operations Concept, Requirements, and Architecture and Design shall be validated to assure mutual consistency.
R-62	Acceptance criteria shall be developed for system end products.
R-63	The systems engineering team shall plan for the availability of products, people and facilities to support product integration at all PBS levels leading to the top level of the PBS prior to transition to the end user.
R-64	Plans for the transition of end products to the next higher PBS level shall be developed, reviewed and maintained.
R-65	The systems engineering team shall plan for the availability of products, people, and facilities for product transition.
R-66	The systems engineering team shall validate the technical data packages and other end product documentation meet Mission Design Requirements.
R-67	The Requirements flow hierarchy shall be consistent with the Product Breakdown Structure. Requirements are decomposed and allocated to products down through the PBS. Ideally, this continues until a single engineer is responsible for the product. Some shared requirements may flow between and across subsystem elements.
R-68	Shared requirements shall be documented either within the requirements tree, or in a separate specification such as Electro-Magnetic Interference (EMI), Environmental, Electrical Systems, Contamination, etc., or as part of Resource Budgets.
R-69	Shared requirements shall be referenced by all elements to which they apply. By the end of Phase C, and the CDR, the requirements flow, down to build-to specifications, should be complete.
R-70	The outcome and decisions for key requirements trade studies and optimizations shall be documented, (Section 5). Trade studies and analysis are used to refine the requirements along with the Operations Concept and the Architecture and Design to meet the Mission Design Requirements including cost and schedule.
R-71	Requirements shall specify the interfaces or reference configured interface specifications.
R-72	A list of all interfaces requiring an ICD shall be documented and maintained.
R-73	The project team shall decide which ICDs are necessary, given the complexity, organization structure, and participants.
R-74	The ICDs shall be validated to the Architecture and Design and the Requirements.
R-75	The Product Manager and the Lead Systems Engineer shall prepare a SEMP that addresses the requirements of this GPR and describes What, When, Where, by Whom, and How each are to be implemented.

Reqt #	Requirement
R-76	Working with the program/project manager, the technical team shall determine the appropriate level within the system structure at which SEMPs are developed, taking into account factors such as number and complexity of interfaces, operating environments, and risk factors.
R-77	The SEMP shall include an organization structure along with responsibilities for the Systems Engineering Team.
R-78	The SEMP shall include major trade studies, which should be identified when the SEMP is baselined during life cycle Phase A and changes captured during subsequent system milestone reviews.
R-79	The SEMP shall include a schedule and list of resources required for the systems engineering effort.
R-80	Discipline Technical Plans shall be validated to the SEMP for consistency.
R-81	Software Development and Management Plans shall be validated to the SEMP for consistency.
R-82	Each project shall identify the mission resources to be allocated and tracked.
R-83	Each project shall define acceptable resource margins and then set up a margin management philosophy based on design maturity and time.
R-84	Each project shall choose the Systems Engineering documents necessary for inclusion in its Configuration Management Office, and the degree of formality assigned to document change control.
R-85	Documents stored in the library shall include the configured, single point of reference for the Operations Concept, Architecture and Design, Requirements, Technical Data and Resource Budgets, Mission Environments, and the Systems Engineering Management Plan (SEMP).
R-86	The systems engineer shall generate a document tree that shows the requirements hierarchy.
R-87	The technical team shall define an approach to manage project technical data, including technical data obtained from any contracted technical effort.
R-88	A Failure Modes and Effects Analysis (FMEA) shall be performed early in the design phase to identify system design problems (flight and ground, hardware and software).
R-89	Fault Tree Analyses (FTA) shall be performed to address both mission failures and degraded modes of operation.
R-90	The Risk Management Plan shall document the project's decision on utilizing PRA and similar techniques in the project systems engineering process.

Reqt #	Requirement
R-91	The results of FMEA's, FTA's and any numerical reliability assessments or predictions shall be reported at system-level critical milestone reviews.
R-92	The methodology to be employed for identifying, performing and documenting trade studies to be conducted shall be identified in the SEMP.
R-93	The Technical team shall identify, track, document the results of key trade studies and integrate the results into mission products.
R-94	Concept development shall include make or buy trades and decisions to optimize mission performance and cost.
R-95	Statements of Work (SOW) shall be developed.
R-96	The SOW shall include the definition of the offerer's SEMP and other work products.
R-97	The SOW shall include technical oversight requirements
R-98	The SOW shall include support activities for product transition and disposal as appropriate.
R-99	A contractor surveillance plan shall be developed to address how the technical effort will be monitored, tracked and reported by the oversight organization.
R-100	Technical evaluation of offerer's proposals shall be performed.
R-101	Technical oversight and reviews, as defined in the SOW, shall be performed.
R-102	The monitoring function for traditional FS&GS projects shall be accomplished using the following required minimum set of technical reviews: Mission Concept Review (MCR), System Requirements Review (SRR), System Definition Review (SDR) and/or Mission Definition Review (MDR), Preliminary Design Review (PDR), Critical Design Review (CDR), Systems Integration Review (SIR), Test Readiness Review (TRR), System Acceptance Review (SAR)/Element Pre-Ship Review (PSR), Observatory Pre-Ship Review (PSR), Operational Readiness Review (ORR) and/or Mission Readiness Review (MRR), Flight Readiness Review (FRR), Operational Acceptance Review (OAR), Post-Launch Assessment Review (PLAR) and Decommissioning Review (DR).
R-103	In addition, the minimum set of mission reviews shall include GSFC specific technical reviews such as the Mission Operations Review (MOR), Pre-Environmental Review (PER), Flight Operations Review (FOR), Launch Readiness Review (LRR), Critical Event Readiness Review (CERR), Safety and Mission Success Review (SMSR), and Mission Readiness Brief (MRB)/MRR that will be employed by the robotic mission projects as shown in Figures 2, 3 and 4 and Table 1 (Key Function 4.10 & Note 3).
R-104	Engineering Peer Reviews, including systems engineering peer reviews, shall be planned and conducted in accordance with GPR 8700.6.

Reqt #	Requirement
R-105	Integrated Independent Reviews shall be planned and conducted in accordance with GPR 8700.4 and GSFC-STD-1001. Required IIRs include the GSFC specific mission reviews and the reviews conducted on defined mission elements and systems (such as spacecraft, instruments and ground systems).
R-106	For all reviews documented in the SEMP, the technical team shall address the entrance and success criteria listed in GSFC-STD-1001 and in Appendix G of NPR 7123.1 for applicability to the respective reviews.

Appendix D - Systems Engineering Management Plan Outline

Note that the SEMP should be updated following each milestone/review; i.e. upon entry to each phase to reflect current information/plans

Signature Page

These may be expanded to include other parties, but the minimum signature set is shown here.

Prepared by: ______________________________

< preparer > *Date*
< title >

Approved by: ______________________________

< 1st level approver/Lead SE > *Date*
< title >

____

< Project Manager Name> *Date*
< title >

____

< DGA Name> *Date*
< title >

1 Introduction

1.1 Purpose and Scope

<< Briefly describe the purpose, scope and content of the SEMP >>

1.2 Applicable Documents

<< List the documents applicable to SEMP implementation. The SEMP details how the technical team will implement the requirements and guidelines of these standards and procedures. Examples include NPRs, GPRs, PGs, project/program documentation >>

1.3 Reference Documents

<< List project specific documents such as: Statement of Work, Contract Data Requirements Lists, Integrated Independent Review Plan and mission-wide lexicon>>.

1.4 Definitions

<< Define terms used within the SEMP. Mission-wide definitions may be provided as a separate appendix or as a reference document >>

2 Mission/Project Information

2.1 Mission Overview

<< Define Mission needs, goals and objectives; describe mission parameters such as mission orbit, launch vehicle, etc. If this "system" is part of a larger "system", describe the "system of interest" function relative to the overall system and how it fits into the overall mission objective. Define mission level roles and responsibilities and the system architecture concept. If this project is part of an overarching program, describe the relationship and agreements made.>>

2.2 System of Interest

<< If applicable, define what this Systems Engineering effort is designing, developing, and delivering in context of the overall mission described above >>

2.3 Current Phase

<< Describe which phase the project is currently in and what activities have taken place up to the point of this document generation/update >>

2.4 Work Plan for Phase

<< Describe the top level work plan for the SE effort for this program/project phase. Include focus/activities planned at top level to achieve the next milestone. Alternatively, this can be addressed under a separate cover document entitled "Systems Engineering Implementation Plan" or for smaller projects may be contained in an updated project plan per phase >>

2.5 System Structure

<< Describe the major system segments such as the space segment, space platform and pre-launch ground support equipment, flight operations segment, data processing and archive segment and launch services segment >>

2.6 Project Schedule

<< Provide the project schedule which is current at the time of release of the SEMP; describe how the technical team will obtain schedule updates as the project evolves. >>

3 Systems Engineering Management

3.1 Team Organization, Roles and Responsibility

<< Define the Systems Engineering Organization Chart and Job Responsibilities. If the responsibility includes contractor work, define the scope of the work. Define Trade studies, topic, who does them and when they are due. Include a top-level schedule for the systems engineering activities including major work previously identified. Describe how the technical effort will integrate with project management and the project plan in allocating resources, e.g. cost, schedule, and personnel, and how changes to the allocations will be coordinated >>

3.2 Specialty Engineering

<< Describe the engineering disciplines which apply across the project and the WBS model of the system structure. Examples include safety, logistics, reliability, quality, sustainability and operability. >>

3.3 Support Integration

<< Describe the team composure in terms of contractor support and implementation contractor(s). Define the division of responsibility among the team in terms of deliverables and how the work will be delineated and ultimately integrated to perform optimal systems engineering.>>

3.4 Team Communications

<< Describe methods utilized for communicating systems engineering activities, progress, status and results. Include any periodic meeting or working groups. Reference communication methods like meeting makers, tracking tools, email, websites, etc. that are planned >>

3.5 Engineering Methods and Tools

<< Describe the methods and tools that are needed to support the overall technical effort and identify those tools to be acquired or licensed; define tool training requirements. >>

3.6 Technology Insertion

<< Describe the approach and methodology for identifying key technologies and their associated risks and the criteria for assessing and inserting technologies into the system, including Make or Buy considerations. Define the approach to selecting new technologies as they mature for insertion in the system over the project life-cycle. >>

3.7 Software Development and Management Plan Integration

<< Reference the project's software development/management plan and describe the approach to ensuring that the software activities are consistent with the SEMP and are accomplished as fully integrated parts of the technical effort >>.

3.8 System Safety

<< Describe the approach and methods for conducting safety analysis and assessing the risks to operators, the system, the environment and the public, as applicable. >>

3.9 Waivers

<< This section contains all project approved deviations and waivers and deviations not related to the GPR 7123.1A. Examples include Gold Rule and other types of deviations/waivers. Note Appendix C addresses GPR 7123.1A related deviations/waivers.

3.10 Additional Information

<< Include any additional information >>.

4 Key Systems Engineering Functions

*<< For each function, describe the approach and define the roles and responsibilities for each organization in accomplishing. If the project integrates support contractors, implementation contractors and/or or other organizations, delineate each entity's role for **each** function while addressing in the following sections. >>*

4.1 Systems Lifecycle Functions

4.1.1 Understanding the Objectives

<< Describe who is responsible for developing the Level 1 Requirements, Mission Success Criteria, and the definition of Minimum Mission. List which document will contain each of these. Define when each of these is due. Define which inter-organizational/inter-agency commitments are required and responsibilities and timing for obtaining them >>.

4.1.2 Mission Environments

<< Define the applicable mission environments, who is responsible for determining the mission specific environmental levels or limits, and how each environmental requirement is to be documented. >>

4.1.3 Operations Concept Development

<< Define who develops the operations concept, what format is planned and when it is due. Define who develops the ground based verification concept, what format is planned and when it is due. >>

4.1.4 Requirements Identification

<< Describe the requirements hierarchy, who is responsible for each part of the hierarchy, define who identifies and is responsible for the crosscutting requirements how the requirements at the level of the SE effort will be identified >>

4.1.5 Mission Architecture and Design Development

<< Define who develops the Architecture and Design, what format is planned and when it is due. Define who develops and maintains the Product Breakdown Structure. Sometimes the total system architecture is prepared by several groups. Defining the roles of each of the participants is important >>.

4.1.6 Product Implementation

<< Define who is responsible for the implementation activity and how the SE organization plans to track the progress and their role in the activities for each level within the requirements hierarchy. >>

4.1.7 Integration

<< Define who is responsible for performing the integration activity and tracking the progress for each level within the architectural hierarchy. Define what tools (if any) are planned to track integration status. Describe the progression of planned integration to arrive at the final "system of interest">>

4.1.8 Verification

<< Define who is responsible for performing the verification activity and tracking the progress for each level within the requirements hierarchy. Define who has approval authority for verification at each level within the requirements hierarchy. Define what tools if any are planned to track verification status. Define the due dates for showing requirements compliance >>

4.1.9 Validation

<< Define who is responsible for the validation activities and how this is accomplished. What analysis or performance predictions are planned, who performs each and how they will be accomplished. >>

4.1.10 Acceptance and Transition

<< Describe how the acceptance criteria for the product will be developed, as well as who is responsible for this task and how responsibilities will be shared among the NASA and contractor technical teams. If the product is planned to be integrated into a larger system, describe the organizational responsibilities and interdependencies to accomplish this task. >>

4.2 Systems Management Functions

4.2.1 Requirements Management

<< Define what format is planned and what tools if any are to be used for documenting and tracking the requirements. Define when requirements identification is due and when formal configuration control is expected to start >>

4.2.2 Interface Management

<< Define which IRDs, IDDs, ICDs are planned, what interfaces are to be included, who is responsible for developing the ICDs and who has approval and configuration management authority >>

4.2.3 Technical Planning

<< Define what areas of technical planning are expected, how cost estimates are developed/validated and who's doing the activities, define how the SE team resources are planned to be utilized/allocated >>

4.2.4 Technical Resource Budget Tracking

<< List the resource budgets Systems Engineering will track, the margin philosophy, who will collect the inputs, how often they will be collected, and when allocation of the budgets are due and when they will be placed under formal configuration management >>

4.2.5 Configuration Management and Data Storage

<< Define the planned configuration management process (or reference the project CM plan) and when it is to be placed under formal configuration management. Define the method to archive and distribute Systems Engineering data and information generated during the course of the life-cycle. Define an approach to manage the acquisition, assessment, dissemination, storage and updating of technical data utilized by the project throughout the system life-cycle. >>

4.2.6 Risk Management

<< Define the plan for Technical Risk Management; who is responsible for defining acceptable risk and where this is documented. Define the role of systems engineering in risk management and how the systems engineering management plan and the risk management plan are related. Define reliability philosophy and what reliability analyses are planned, who is responsible and how the analyses are to be accomplished, including any special tools. Define when and how often reliability analyses are due. >>

4.2.7 Decision Analysis

<< Define the decision analysis methodologies to be used in identifying key decisions and the decision analysis methodologies, e.g., from the NASA Systems Engineering Handbook, SP-6105, Revision 1, to be employed in reaching decisions. Define the plans for recording and archiving results of Trade studies. >>

4.2.8 Acquisition Support

<< Define who is responsible for providing support for project acquisition activities over the project life-cycle and the resources required to provide this support. Provide a description of how the technical effort of in-house and outside contractors is to be integrated with the GSFC technical team effort >>

4.2.9 Additional functions

<< Include any additional planned SE functions and how/who/what is planned >>.

5 Systems Engineering Lifecycle Activities

<< Describe the overall lifecycle including the major systems engineering activities for each phase irrespective of who does them. Describe critical decisions and activities. Include approach for performing the systems engineering activities especially where subcontracts are planned. If Phase is already completed, describe the accomplishments in each area. Complete

the following table to address the Key Systems Engineering Functions for each phase (Pre-A/A/B/C/D/E/F) in terms of planned activities and where the activity will be documented. ***Alternatively*** *each function may be expressed as a table progressing through each phase to demonstrate the continuity of activities.>>*

	Systems Engineering Activities	*Planned Documentation*
Understanding the Objectives		
Mission Environments		
Operations Concept Development		
Requirements Identification		
Architecture and Design Development		
Implementation		
Verification		
Validation		
Acceptance and Transition		
Requirements Management		
Interface Management		
Technical Planning		
Technical Resource Budget Tracking		
Configuration Management and Data Storage		
Risk Management		
Decision Analysis		
<Add'l functions described in Section 4>		

5.1 (Pre-Phase A)

<< Supply info above >>

5.2 Phase A

<< Supply info above >>

5.3 Phase B

<< Supply info above >>

5.4 Phase C

<< Supply info above >>

5.5 Phase D

<< Supply info above >>

5.6 Phase E

<< Supply info above >>

5.7 Phase F

<< Supply info above >>

6 Systems Engineering Reviews and Deliverables

6.1 Milestone Reviews and Deliverables

<< Define which systems engineering reviews are planned, who is responsible for organizing them. >>

<< Provide a summation of project Systems Engineering deliverables, as determined from review of GSFC-STD-1001 Criteria for Flight Project Critical Milestone Reviews, GSFC-STD-1000 "Gold Rules", and others as applicable. Typical information to be provided includes source of information, deliverable items, responsibility and timing by life-cycle phase >>

<< Complete following table per phase – at a minimum include all required deliverables per the NPR 7123.1A, and include rationale if not being generated >>

Document Number	*Deliverable Document Name*	*Systems Responsibility*	*Status*
<Insert Number>	*<Insert Document Name>*	*Describe what role Systems has in this document << generate/update/review/approve >>*	*Indicate what rev the document will be in this release or rationale for omission*

6.2 Peer Reviews

<< Define Engineering Peer Reviews that are planned/have been completed by filling in the table below >>

System/ Subsystem	*Area Lead*	*Peer Review Chairperson*	*Date Planned/Completed*	*Status*	*Document Number*
				Planned/ Complete	

Appendix A

A.1 Compliance Matrix

<< Complete the matrix below to address each of the 106 requirements identified in the GPR and the project intended compliance for each. Where a deviation is requested, Section A.2 will include a discussion as to the specific request.>>

Reqt #	Compliance (Green = Fully Compliant Yellow = Deviation Requested Grey = Not Applicable)	Notes (If deviation, describe below and indicate; if not applicable - explain)
R-1		
R-2		
R-3		
R-4		
R-5		
R-6		
R-7		
R-8		
R-9		
R-10		

A.2 Additional Information on Compliance Matrix

This section should address any tailored GPR requirements, deviations requested and determinations for non-applicability. Deviation Requests should include a rationale for the request and identify the specific SEMP section or sub-section which addresses the deviation and plans to address the tailoring. >>

Appendices

<< Appendices may be included, as necessary, to provide information such as a glossary of terms, acronyms and abbreviations, information applicable to several SEMP sections and lengthy, but separable, write-ups which would disrupt the flow of the SEMP if included in the main text. >>

Appendix E - Tailoring Guidelines

E.1 Tailoring: Who Performs the Functions Listed in This GPR?

An important part of Systems Engineering is planning the systems engineering activities, what is done, who does them, how it is to be done, and when the activities are expected to be complete. The purpose of the Systems Engineering Management Plan is to document the results of the planning process. The planning is especially important when systems engineering activities are spread out over multiple organizations and contractors.

The basic principles behind the major functions described in this GPR are more or less universal. Tailoring addresses who is responsible and the degree to which the customer has insight into how the functions are accomplished.

When work is performed via contracts, each project needs to make clear the delineation of responsibility between contractors and customers, and the degree of insight, verification and approval authority of the customer. It is critical that the statements of work include the expected systems engineering activities, and appropriate deliverable products that provide customer insight into progress and results.

Guideline for choosing the degree of verification for systems engineering activities:

a. Consider the project unique acceptable risk when deciding whether to require documentation or verification that the systems engineering activities have occurred. If the particular systems engineering activity has a large impact on mission success, if not performed properly, then customer verification may be necessary.

b. Insight should scale with the potential loss of the Government Furnished Equipment (GFE) or loss of customer investment. With a large potential loss, there may be a need for insight into systems engineering activities.

c. Insight could also scale with the required timeliness of the data provided by the end product. For critical data loss there may be a need for insight into systems engineering activities.

For instrument developments, the Instrument Manager's role is similar to the Project Manager's in that they are responsible for the formulation and implementation of the "instrument" project per NPR 7120.5. The Instrument Manager should work with the Program/Project Manager or designee, depending on their project structure, in tailoring GPR 7123.1 for their instrument development.

E.2 Tailoring Systems Engineering Functions to the "System of Interest"

The decision whether certain systems engineering functions should not be performed should be consistent with the acceptable level of risk agreed to by the project and its customer. See Appendix F – Applicability of Key Functions vs. Risk Classification.

The basic principles behind the major functions are more or less universal. Generally it is not a question whether a function is to be performed, but who is responsible and the degree to which the customer has insight into how the functions are accomplished. See Appendix E.1 above.

There are cases where the system of interest is a portion of a total space mission and hence the systems engineering functions are appropriately tailored to the system of interest.

Appendix F – Applicability of Key Functions vs. Risk Classification

Key Functions	Class A	Class B	Class C[1]	Class D[1]
4.1.1 Understanding the Objectives	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Less formal mission success criteria**
4.1.2 Mission Environments	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Relaxation of environmental analyses based on mission duration**
4.1.3 Operations Concept Development	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Less formal operations concept**
4.1.4 Requirements Identification	**Full Compliance**	**Full Compliance**	**Full Compliance**	**The approach to Key Function 4.1.4 will be prescribed in the SEMP.**
4.1.5 Architecture & Design Development	**Full Compliance**	**Full Compliance**	**Less formal architecture development**	**Less formal architecture development**
4.1.6 Product Implementation	**Full Compliance**	**Full Compliance**	**Full compliance**	**Less stringent tracking required**
4.1.7 Integration	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Less formal integration plan**
4.1.8 Verification	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Simplified verification tracking; no requirement to follow GEVS**
4.1.9 Validation	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Simplified verification tracking; no requirement to follow GEVS**
4.1.10 Acceptance & Transition	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Less formal acceptance process**
4.2.1 Requirements Management	**Full Compliance**	**Full Compliance**	**Full Compliance**	**The approach to Key Function 4.2.1 will be prescribed in the SEMP.**
4.2.2 Interface Management	**Full Compliance**	**Full Compliance**	**Full Compliance**	**The approach to Key Function 4.2.2will be prescribed in the SEMP.**
4.2.3 Technical Planning	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Smaller SEMP; Less cost complexity**
4.2.4 Technical Resource Budget Tracking	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Full Compliance**
4.2.5 Configuration Management and Data Storage	**Full Compliance**	**Full Compliance**	**Full Compliance**	**Less formal configuration control and no requirement for a document tree**
4.2.6Risk Management	**Full Compliance**	**Full Compliance**	**Relax requirement for FMEA, FTA, PRA**	**The approach to Key Function 4.2.6 will be prescribed in the SEMP.**
4.2.7 Decision Analysis	**Full Compliance**	**Full Compliance**	**No formal decision analysis process required**	**No formal decision analysis process required**

[1] See P.2.1 for applicability of risk levels to Class C and D missions.

4.2.8 Acquisition Support	**Full Compliance**	**Full Compliance**	**Less oversight of contractor effort**	**Less oversight of contractor effort and units and parts acquisitions are subject to reduced production data deliverables**
5.0 System Milestone Reviews	**Full Compliance**	**Full Compliance**	**If approved by the DGA, reviews may be combined for increased efficiency**	**The System Milestone Reviews requirements will be tailored and approved by the appropriate technical authority and documented in the program/project SEMP." The IIR program may be compressed by combining the PDR's and CDR's for the spacecraft and mission into one review, and removing the SIR as a required review.**

CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes
Baseline	06/29/04	Initial Release of GPR 7120.5
A	01/10/05	As directed during the FY04 Center Rules Review, the Responsible Office modified this document to remove requirements that were no longer needed and to clearly distinguish requirements from supporting information. Administrative changes were made throughout to correct responsible organization names and codes, and to retitle Goddard Procedures and Guidelines (GPR) to Goddard Procedural Requirements (GPR). All changes were reviewed and approved by the Goddard Quality Management System Council (QMSC).
Rebaselined as GPR 7123.1	8/15/08	This GPR was modified to bring it into compliance with NPR 7123.1A in accordance with the Goddard's NPR Implementation Plan.
A	8/16/10	Redefined System Processes Added references to 599-SUR-100 and 599-IP-100; removed Appendix F (addressed in 599-SUR-100). Added documentation emphasis Updated SEMP Outline