Requirements Management Plan

020.10.15.00.00-0001-PLA-REQS_MGMT_PLAN

Status: **RELEASED**

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Change Record

Version	Date	Author	Reason
1	2017-10-06	Treacy	Initial Draft.
2	2017-10-10	Treacy	Incorporate peer review feedback.
3	2018-03-14	Treacy	Minor edits, update to diagram in Sec 4.2.
4	2018-10-02	Treacy	Added verb conventions to Sec 3.3, other minor edits.
5	2019-02-05	Cosper	Incorporate edits/RIDs following IPDSR, JIRA IPDSR-523 not implemented, need guidance on specific tool dependencies in high level planning docs, IPDSR-521 not implemented, propose baseline be defined and controlled under PM Plan.
6	2019-08-09	Leyba-Newton	Edits for StRR package; reconciling feedback from M. Stewart.
7	2019-08-13	Selina	Edits throughout for StRR package. Synced requirements categories and level definitions.
A	2019-08-27	Lear	Incorporated edits by M. McKinnon; prepared document for signatures and release.
A.1	2020-05-13	Leff	Added flow-down diagram in Appendix; updated subsystem requirements identifiers.
B	2020-05-15	Lear	Routed document for final revisions; prepared PDF for release.
C	2022-01-28	Kusel	Updated to align with the latest SEMP for System CDR: - Minor addition to section 3.4 - Rewrite of section 3.5 to align with the SEMP. - Rewrite of section 3.8 to align with the SEMP. - Update of table in section 3.9.2 to add missing items. - Update of section 4.2 to align with latest requirements documents.

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1 Introduction

Requirements management is the process of discovering, organizing, documenting, analyzing, tracing, and agreeing on requirements, and then controlling and coordinating requirements changes. Requirements management is a continuous process that occurs throughout the ngVLA system lifecycle. As outlined in the Systems Engineering Management Plan (SEMP) [AD01], the Systems Engineering staff is responsible for overseeing and implementing the requirements management process on the ngVLA project, which includes managing and configuring the Requirements Database.

1.1 Purpose

This plan provides a common language and structured framework for the purpose of managing requirements at all levels to ensure all stakeholder needs are satisfied and regulatory compliance is met.

A clear hierarchy of requirements begins with science goals and use cases, also including high-level stakeholder and regulatory requirements, decomposition to system and subsystem-level requirements, and further decomposition to assembly, sub-assembly, and component-level requirements. Requirements at each of these levels also include metrics, which serve as the basis for verification and validation.

Requirements Management is a discipline that uses precisely defined terms to ensure all stated requirements incorporate requirements management best practices. Terms used in requirements discussions can sometimes be ambiguous or easily misinterpreted. This document, in conjunction with the ngVLA Lexicon [AD03], will define terms used in ngVLA documentation.

Many best practices for requirements management exist across the landscape of research, corporate, military, and government engineering communities. ngVLA has selected and adopted best practices that fit well within the ngVLA project structure and also satisfy stakeholders. This plan is intended to provide guidance to the Integrated Product Teams (IPTs) producing requirements and other design deliverables so that they can best support project objectives.

This Requirements Management Plan is a subsidiary document to the SEMP [AD01]. Requirements Management spans multiple systems engineering processes as described in the SEMP, but the complexity of these processes is consolidated into a coherent plan.

This plan defines the overall requirements hierarchy, requirement levels, identification scheme, metrics, relationships to the Work Breakdown Structure (WBS) [AD02], responsibilities, and other criteria used to plan and manage requirements. Management and clear definition of requirements is intended to prevent gaps in the system design, avoid duplication of effort, and promote the clear definition and delivery of each requirement. Requirements developed under this plan lead to a clear understanding of subsystem contributions to the overall system specification, so trades can be made to optimize performance at the lowest cost.

1.2 Scope of this Document

To assure consistency across many system specification and requirements documents, provisions in this plan apply to the entire ngVLA project. Several layers of abstraction exist between the science use cases and component-level definitions. This plan will define each layer and describe relationships and traceability between layers. Every ngVLA technical team shall adhere to the Requirement Change Management process outlined in this document. This document does not contain any requirements; they are located in the Requirements Database. This document does not cover formal reviews, testing, integration, validation, verification, acceptance testing, or commissioning, although requirements are essential to each of those processes.

2 Related Documents

2.1 Applicable Documents

Ref. No.	Title	Doc. No.
AD01	Systems Engineering Management Plan	020.10.00.00.00-0001-PLA
AD02	Work Breakdown Structure	020.05.05.00.00-0007-WBS
AD03	Project Lexicon	020.10.10.10.00-0005-LIS

2.2 Reference Documents

Ref. No.	Title	Doc. No.
RD01	INCOSE System Engineering Handbook 4th Ed.	INCOSE-TP-2003-002-04
RD02	INCOSE Guide for Writing Requirements Ver. 2	INCOSE-TP-2010-006-02
RD03	Assembly Integration and Verification Concept	020.10.05.00.00-0005-PLA
RD04	Configuration Management Plan	020.10.10.15.00-0001-PLA
RD06	Stakeholder Requirements	020.10.15.01.00-0001-REQ
RD07	Science Requirements	020.10.15.05.00-0001-REQ
RD08	System Requirements	020.10.15.10.00-0003-REQ

3 Requirements Management Strategy

3.1 Definition of Requirements

A requirement is a condition or capability of a system that describes the needs of the customer. In addition, requirements may be derived from or based upon other requirements in order to assist in providing a common understanding of the desired characteristics of a system. For ngVLA, the customer is the National Science Foundation and, by extension, the greater astronomical scientific community.

ngVLA Requirements can be classified into three broad *categories* as either Stakeholder Requirements, System Requirements, or Technical Requirements. Stakeholder Requirements and System Requirements state what the system will do, and Technical Requirements state what the subsystems, assemblies, subassemblies, and components will do.

- **Stakeholder Requirements** exist at the top level of the requirements hierarchy and consist of requirements inherited from the customer, which can be the funding agency or the scientific community, and other key project stakeholders. Stakeholder Requirements also include requirements from the Observatory that dictate interfaces to existing systems and processes at any stage of the lifecycle, and regulatory requirements from appropriate agencies with supervisory responsibility over the project. Stakeholder Requirements can include, but are not limited to, Key Science Goals, Science Use Cases, science data quality needs, the system's operational lifetime, and operational availability. Stakeholder Requirements are validated by system-level validation and commissioning.
- **System Requirements** are high-level requirements that usually apply to more than one part of the system and typically affect more than one IPT. ngVLA system-level requirements, safety requirements, and environmental requirements are all classified as System Requirements due to their wide-ranging impact. System Requirements are derived from Stakeholder Requirements providing more detail around what the system will do to meet the stated science objectives. System Requirements are verified by system-level integration and verification testing, and some validation testing.
- **Technical Requirements** are lower-level requirements that apply to one part of the system and typically affect one IPT. Technical Requirements capture what is required to design, implement, and construct the system. Technical Requirements are verified by component-level or unit-level testing.

The ngVLA Requirements also map to three defined levels, indicative of their degree of abstraction:

- **Level 0 (L0)** requirements are expressed in the customer or stakeholder language and express their needs or use cases. These requirements are typically in the Stakeholder Requirements category.
- **Level 1 (L1)** requirements are expressed in technical functional or performance terms, but are still implementation agnostic. These requirements are typically System Requirements.
- **Level 2 (L2)** requirements define the specification for an element of the system, presuming a system architecture. Technical Requirements are typically written at this level for sub-systems, assemblies, sub-assemblies and components.

While the requirements levels typically map to the appropriate categories, a clear and traceable requirements flow-down and derivation will necessitate exceptions. For example, some System Requirements may, by necessity, be written as L2 Requirements.

The Stakeholder and System Requirements categories (whether expressed as L0 or L1 requirements), are the responsibility of the ngVLA Systems Engineering team working in close coordination with the Project Scientist and Project Engineer.

Technical Requirements are further decomposed within the IPTs to lower levels and are the responsibility of the subsystem IPTs during the Detailed Design and Prototyping Stage of the ngVLA System Lifecycle Model.

3.2 *Sources and Integrity of Requirements*

Requirements are developed in a top-down yet highly iterative process, shown in Figure 1. A detailed requirements flow-down diagram (Figure 2) as of the Conceptual Design Stage is presented in the Appendix. Intermediate requirement levels (0.1, 1.1, 2.1) are used to indicate documents or artifacts that relate to associated requirements documents but do not fit into the defined levels.

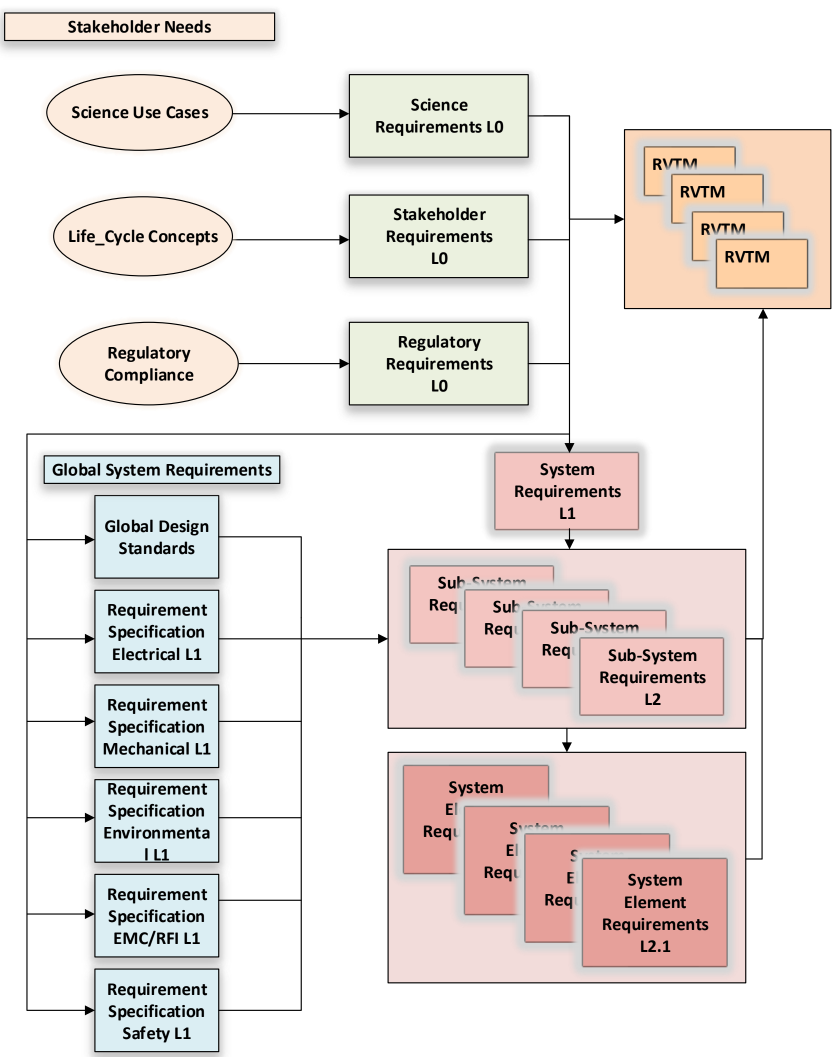

Figure 1 - Schematic representation of ngVLA requirements management strategy.

- Science Use Cases reflect science needs, which are translated to capabilities which the system must provide.

- The ngVLA Lifecycle Concepts reflect the needs that must be considered for all phases of the system/instrument's life, as well as all levels of requirements definition (e.g., construction, deployment, operations, maintenance and support, disposal and reclamation).
- Stakeholder and Regulatory Requirements are analyzed and transformed into a technical view that meets project objectives in a set of System Requirements that is not constrained to a particular design solution.
- Alternative solutions are traded against cost, performance, risk, and other constraints. Design choices are down-selected from the trade space, defined in a complete set of Subsystem Requirements.
- Subsystem Requirements are further decomposed within the IPT to the system element/assembly, subassembly, and component-level requirements (e.g., at the module level), where alternative trades on design solutions are made.

Once a requirement set reaches a certain level of completeness and consistency, it will be baselined. Any further changes are subject to change control which can result in updating the technical baseline. Ongoing discovery of requirements is almost certain. However, changes to requirements will have a more significant impact on the project schedule and budget baselines the further into the project that changes occur.

3.2.1 Requirements Database

Requirements will be stored and baselined in a requirements database that is sufficient in size and capabilities to meet the needs of the ngVLA project.

3.3 Discovering Requirements

Requirement discovery involves eliciting new requirements via decomposition from inherited customer requirements, working groups, advisory committees, formal reviews, and document research and mining. Individual requirement statements are defined by the following characteristics for well-formed requirements (INCOSE SE Handbook [RD01], Guide to Writing Requirements [RD02]):

- Necessary
- Appropriate
- Unambiguous
- Complete
- Singular
- Achievable/Feasible
- Verifiable
- Correct
- Consistent/Conforming

The full expression of a well-formed requirement may include associated attributes, which are described separately from the requirement statement. The purpose for inclusion of attributes is to prevent overloading the requirement statement with details that inherently obfuscate the requirement statement but support the characteristics noted above. Attributes may also provide information needed for tracking progress in fulfilling and verifying the requirement.

Requirements attributes to help define the requirement and its intent may include:

- Rationale for the requirement.
- Verification details, states, modes conditions for operational use.
- Verification method (see the Verification and Validation section below for more on methods).

- Verification phase, which indicates when the requirement is tested. Verification phases are listed and defined in the Verification and Validation Plan [RD03].
- Verification result after tests have been conducted.
- Bi-directional linking/traceability to parent(s), children, peers, and origin at the stakeholder level (L0).
- Link type, which indicates if a requirement helps satisfy a requirement on a higher level, or if a reference is being established between requirements, meaning if one requirement changes it helps the systems engineer know to review linked reference requirements as they may be impacted as well. There can also be test links so test case numbers can be linked to requirements, and logic can be built in to change the requirement's verification result once all linked tests have been conducted.
- Link rationale, which is a text entry explaining who created a link between requirements and why that link should exist. This is important because some links can partially satisfy another requirement vs. fully satisfy, and there are also strong vs. weak links as well as non-obvious reasons that requirements should be linked.
- Associated metrics, with emphasis on the Key Performance Parameters (KPPs).
- Requirements type, such as safety, environmental, interface, reliability, availability, etc.
- Type/category; L0/L1/L2, Stakeholder, System, Subsystem.
- Unique Identifier, Unique Name.
- Approval date, owner/entity responsible to fulfill the requirement (typically at the document level).
- Requirement status, as in draft, in-review, or released/baselined.
- Change record identification, dates and reasons for previous changes (typically at the document level).
- General notes, which is a place for systems engineers to add notes that don't fit in other attribute categories in this list, such as action items from reviews or notes on what information is needed to complete a requirement, etc.

Verb Conventions:

- ***Shall*** is used to dictate the provision of a functional capability.
- ***Must*** or ***Must not*** is most often used to establish performance requirements or constraints.
- ***Is required to*** is often used as an imperative in specifications statements written in the passive voice.
- ***Are applicable*** is normally used to include, by reference, standards or other documentation as an addition to the requirements being specified.
- ***Responsible for*** is frequently used as an imperative in requirements documents that are written for systems whose architectures are already defined. As an example, "The XYZ function of the ABC subsystem is responsible for responding to PDQ inputs."
- ***Will*** is generally used to cite things that the operational or development environment are to provide to the capability being specified. For example, "The building's electrical system will power the XYZ system." It can also be used to indicate a future task, for example, "An ICD will be prepared."

The ngVLA Systems Engineer shall come to agreement with the authors of requirements and IPT Leads to select the appropriate attributes for ngVLA. Attributes shall be used consistently within the context of a requirement specification or set of requirements.

Not all information will be available early in the requirements definition process; therefore, details will be lacking and requirements may not be complete or stable. Requirements will be flagged that are in a draft stage, and systems engineers will use an attribute to record requirements status along with what information is needed to complete a requirement. To the best extent possible, the characteristics of well-formed requirements apply at all levels of requirement maturity.

3.4 Requirement Specifications

A Requirement Specification document identifies a set of requirements associated by a common purpose (system, subsystem, facility, procurement, or other related criteria) that ensures the requirement set collectively provides for a feasible solution that meets stakeholder intentions and constraints.

L0 and L1 requirements specifications are generally associated with the system as a whole, while L2 and lower level requirements specifications are related to specific products that are identified in the Product Breakdown Structure.

A requirement set may be defined for several reasons:

- Stakeholder or System Requirements that apply across the entire system/instrument are written in a general way, then allocated to the system, subsystem, or system element requirements as they specifically apply to a particular design solution.
- A requirement set may be grouped by association with a particular emphasis such as safety, general electrical, general mechanical, quality, electromagnetic compatibility, environmental, subsystem performance, facility, procurement, or other related criteria.
- A requirement set may be a subset of the Stakeholder Requirements Specification (StRS), the System Requirements Specification (SRS), or the Regulatory Requirements Specification (RRS).
- A requirement set may be developed to ensure compliance with global requirements and design standards.

No single requirement exists in isolation, outside of a requirements set. A complete set of all requirements for a specific system shall fully define all criteria needed to specify, verify, deliver and validate the system. The complete requirements set will be defined within a hierarchical framework that clearly defines relationships between all sets of requirements. To facilitate hierarchical traceability, decimals may be used to distinguish relative position in the hierarchy. For example, System Requirements at the L2 level may be designated as L2.1, while subsystem requirements are designated L2.2 and sub-assembly levels as L2.3 to maintain hierarchical traceability.

3.5 Interface Requirements

Interface requirements management is defined in [AD01]. Interface requirements will not be defined in Interface Control Documents, but Subsystem teams will derive important interface requirements as part of the requirements analysis and capture these in their respective subsystem requirements.

3.6 Analysis of Requirements

Requirements analysis involves positioning requirements within the ngVLA requirements structure; populating or updating the attribute columns associated with each requirement; linking lower-level requirements to higher-level requirements; conducting requirements traceability analysis; linking test cases to requirements and tracking the status of those test cases; baselining the Requirements Database; identifying areas where requirement updates are needed; identifying areas where requirements are needed; and querying the Requirements Database and producing reports as needed. Requirements analysis is a complex and iterative process which also includes the following.

- Review requirements against criteria for a well-formed requirement.
- Assign priorities amongst requirements.
- Review for conflicts with, or impacts on, other requirements.
- Review for duplication of other requirements, exercise reuse where possible.
- Review for gaps.

- Review against system budgets for power, gain, noise temperature, or other parameters subject to system-wide constraints.
- Perform trades, cost-benefit, and constraint evaluation.

Given the iterative nature of the analysis process, both top-down and bottom-up passes are usually needed to complete a comprehensive analysis.

The analysis process used for ngVLA shall be captured and documented in an analysis report to generalize and disseminate as a project best practice (if applicable), contribute to the project lessons learned, and generally advance the observatory knowledge base.

3.7 Verification and Validation

Verification and validation (V&V) are associated with testing and acceptance events. Please refer to the ngVLA Verification and Validation Plan [RD03] for a description of V&V processes and activities.

Requirements are traced through acceptance with one of four verification methods (IADT):

- I – Inspection
- A – Analysis
- D – Demonstration
- T– Test

These verification methods are further described in [RD03].

3.8 Traceability of Requirements

Requirements traceability ensures that all the system requirements are implemented and that there are no gaps in the design. It also ensures that the verification process is complete. It also enables a thorough assessment of the impact of changes by tracing the changes through the requirements hierarchy.

Three different types of requirements traceability shall be implemented, as defined in [AD01]:

a) Requirements to requirements traceability: through the hierarchy of the system. The flow-down of requirements generally follows the structure of the Product Breakdown Structure (i.e. user to system to subsystem to component requirements). This traceability ensures that all the system level requirements flow down to the applicable subsystems and component specifications. The traceability is implemented in the requirements management tool and can be exported as a requirements traceability matrix.
b) Requirements to design traceability: The completeness of a design is assessed to check (1) that the design addresses all the requirements and (2) that the design derives requirements of lower level components through performance budgets and functional analysis. This traceability is implemented through a compliance matrix that is presented at the detail design phase. The compliance matrix of a system identifies where in the system design each requirement is addressed.
c) Requirements to verification traceability: is needed to ensure that the system/product is fully verified for all its requirements. This is implemented through a verification matrix in the requirements specification document.

3.9 Itemization of Requirements

3.9.1 Unique Requirement ID

Each requirement shall be assigned a Unique Identifier (ID) of the form:

AAANNNN

Where:

- AAA is a unique three letter classification code to distinguish the type of the requirement or the relevant specification (including but not limited to Stakeholder Requirements [RD06], Science Requirements [RD07], System Requirements [RD08], subsystem, facility, performance area, technical specification).
- NNNN is a sequentially assigned number within a requirement set tied to the document structure for simplicity's sake (this makes it easy to add requirements as the documents mature).
- In addition to being unique, requirement IDs are static once assigned and therefore not always in sequential order due to subsequent revisions of the associated requirements document. If a requirement is retired, then the ID is retired as well and not reused, since some documents, drawings, etc. can refer to only the requirement ID and not include the text.

3.9.2 Allowable Classification Codes

Level	Code	Requirement Type
L0	LRC	Land Use and Regulatory Compliance
	SAF	Safety Requirements
	SCI	Science Requirements
	STK	Stakeholder Requirements
L1	AAC	Antenna Array Configuration Requirements
	EMC	Electromagnetic Compatibility Requirements
	ENV	System Environmental Requirements
	RFI	Radio Frequency Interference Requirements
	SYS	System Requirements
L2	ANT	Antenna Requirements
	ATF	Antenna Time and Frequency Requirements
	BMR	Bins, Modules, and Racks Requirements
	CRY	Cryogenic Requirements
	CSP	Central Signal Processor Requirements
	DSC	Data Center & Science Center Requirements
	DSS	Development Support Subsystem Requirements
	DST	Datastores Requirements
	EEC	Antenna Electronics Environmental Control System Requirements
	FED	Front End Requirements
	FIB	Fiber Infrastructure Requirements
	HIL	Monitor and Control Hardware Interface Layer Requirements
	INF	Array Infrastructure Requirements
	IRD	Integrated Receiver and Downconverters Requirements
	MCL	Monitor and Control System Requirements
	MON	Environmental Monitoring Requirements
	MSS	Maintenance and Support Subsystem Requirements
	NSB	ngVLA Site Buildings Requirements
	OFF	Offline Subsystem Requirements
	ONL	Online Subsystem Requirements
	OPS	Operations Buildings Requirements
	PMN	Proposal Management System Requirements

	PSU	DC Power Supply Requirements
	RTD	LO Reference and Timing - Distribution Requirements
	RTG	LO Reference and Timing - Generation Requirements
	SBA	Short Baseline Array Antenna Requirements
	WVR	Water Vapor Radiometer Requirements
L3	CSF	CSP – Switched Fabric
	DBE	CSP – Digital Back End
	SBP	CSP – Sub-Band Processor
	PSE	CSP - Pulsar Engine

Additional classification codes will be added as necessary to capture the project requirement specifications.

3.10 Changes to Requirements

Requirement change management involves reviewing and approving proposed changes to requirements and baselining the affected requirements sets. The requirements change management process is administered through configuration management's change management process and system. Changes to approved requirements are subject to change control processes defined in the Configuration Management Plan [RD04].

4 Appendix

4.1 Acronyms and Abbreviations

Acronym	Definition
IADT	Inspection, Analysis, Demonstration, Test
ICD	Interface Control Definition
INCOSE	International Council on Systems Engineering
KPP	Key Performance Parameters
IPT	Integrated Product Team
L0	Concept, Use Case, and Stakeholder-Level Requirement
L1	System-Level Requirement
L2	Subsystem-Level Requirement
ngVLA	Next Generation Very Large Array
NSF	National Science Foundation
RRS	Regulatory Requirements Specification
RTM	Requirements Traceability Matrix
SEMP	Systems Engineering Management Plan
SRS	System Requirements Specification
StRS	Stakeholder Requirements Specification
V&V	Verification and Validation
WBS	Work Breakdown Structure

4.2 Requirements Flow-Down Diagram

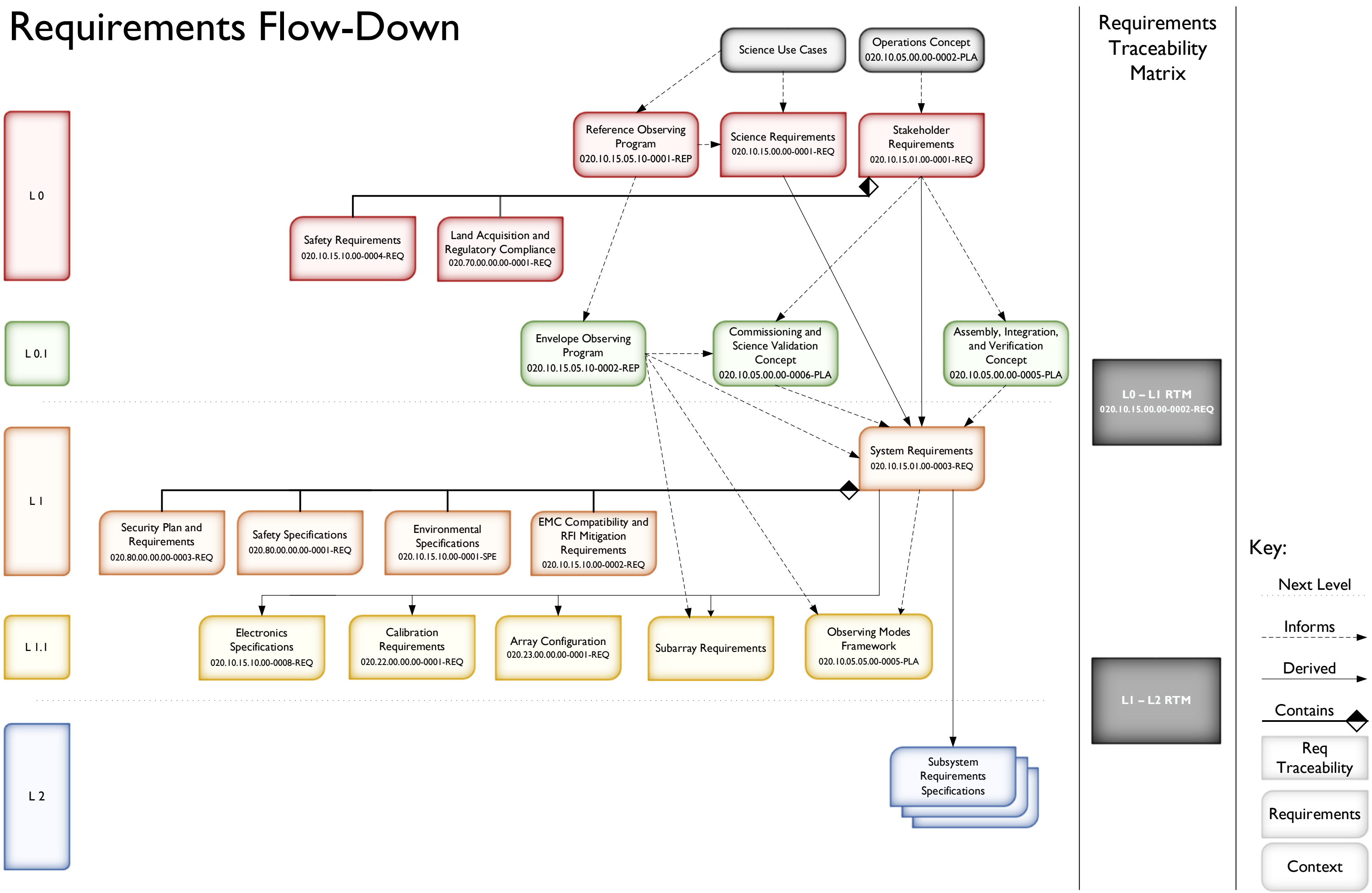

Figure 2 – Requirements flow-down diagram as of Conceptual Design Stage.

020.10.15.00.00-0001-PLA-RevC-REQS_MGMT_PLAN

Final Audit Report 2022-02-08

Created:	2022-02-07
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Status:	Signed
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"020.10.15.00.00-0001-PLA-RevC-REQS_MGMT_PLAN" History

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2022-02-08 - 8:20:13 AM GMT