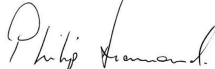




SKA SYSTEM ENGINEERING MANAGEMENT PLAN

Document number.....SKA.TEL.SE-SKAO-MP-001
 Revision.....1
 Author TJ Stevenson & Jason Spyromilio
 Date..... 2013-03-10
 Status Released

Name	Designation	Affiliation	Date	Signature
Owned by:				
TJ Stevenson	System Engineer	SKA Office		
Authorised by:				
Jason Spyromilio	Head of Project	SKA Office		
Released by:				
Philip Diamond	Director-General	SKA Office		

DOCUMENT HISTORY

Revision	Date Of Issue	Engineering Change Number	Comments
A	2012-11-01	-	First draft release for internal review – based on WP2-005.010.030-MP-001 Rev F dated 2011-02-14
B - C	2012-11-05	-	Updates following internal review.
D	2012-11-15	-	Final update. Approved for release in support of the SKA System Engineering review.
E	2013-02-27	-	Revised in line with SE Review recommendations
1	2012-3-10	-	Released for RfP

DOCUMENT SOFTWARE

	Package	Version	Filename
Wordprocessor	MsWord	Word 2010	SKA-TEL.SE-SKAO-MP-001-E_SEMP.docx
Block diagrams	MsVisio	Visio 2007	SEMP (Rev D) Drawings.vsd

COMPANY DETAILS

Name	SKA Organisation
Physical/Postal Address	Jodrell Bank Observatory Lower Withington Macclesfield Cheshire SK11 9DL Registered in England & Wales Company Number: 07881918
Fax.	
Website	www.skatelescope.org

TABLE OF CONTENTS

1	INTRODUCTION.....	7
1.1	Purpose of the document	7
1.2	Scope of the document.....	7
2	REFERENCES	8
2.1	Applicable documents.....	8
2.2	Reference documents	8
3	INTRODUCTION.....	12
3.1	System Engineering in the context of the SKA.....	12
3.2	Project Phases and Transitions	12
3.3	General System Engineering Philosophy	15
4	SYSTEM ENGINEERING PROCESS PLANNING	16
4.1	SKA Organisation Responsibilities and Relationships	16
4.2	Integration of the global System Engineering Effort	16
4.3	Verification Programmes	17
4.4	System Breakdown	17
4.5	Major Deliverables.....	19
4.6	Engineering Standards and Procedures.....	21
4.7	Constraints	21
5	SYSTEM ENGINEERING PROCESS AND APPLICATION	21
5.1	Tailoring	21
5.2	System Engineering Process	21
5.3	Application of the System Engineering Process.....	26
6	SYSTEM ENGINEERING ACTIVITIES	31
6.1	Project Glossary	31
6.2	Work Breakdown Structures.....	31
6.3	Interface Management	31
6.4	Data Management	32
6.5	Reviews and Audits	32
6.6	Requirements Traceability	37
6.7	Baseline establishment	37
6.8	Configuration Management.....	37
6.9	Change Management.....	38
6.10	Logistics.....	38
6.11	Quality.....	38
7	TRANSITIONING HIGH RISK TECHNOLOGIES	39
8	ADDITIONAL SYSTEM ENGINEERING ACTIVITIES.....	40
8.1	Tools.....	40
8.2	Safety	40
8.3	Standardisation	40
8.4	Obsolescence	40
8.5	Human Engineering.....	40
8.6	Redundancy	41

LIST OF FIGURES

Figure 1: The temporal correspondence between SKA Project and SKA System Engineering phasing compared to industrial standard phasing.....	14
Figure 2: The systems engineering process.	22
Figure 3: Requirements analysis process.....	24

LIST OF TABLES

Table 1. An example of a vertical slice through the hierarchy of products	17
Table 2 System Engineering WBS for Stage 1 of the Pre-Construction Phase.....	32
Table 3 Technology Readiness Levels Definitions.....	39

LIST OF ACRONYMS

AAVP.....	Aperture Array Verification Programme
AFR	Africa
AIP	Advanced Instrumentation Programme
ANZ.....	Australia and New Zealand
APERTIF	APERTure Tile In Focus
AR.....	Acceptance Review
ASKAP.....	Australian Square Kilometre Array Pathfinder
ATP	Acceptance Test Procedure
ATR.....	Acceptance Test Result
BD.....	Baseline Design
BIT	Built In Test
BO&E.....	Build Out & Evolution (Extensibility from SKA1 to SKA2)
CCB.....	Change Control Board
CDR.....	Critical Design Review
COAR	Consolidated Observation Action Register
CoDR.....	Concept Design Review
DAA	Dense Aperture Array
D&D.....	Design & Development
DRM	Design Reference Mission
EMBRACE	Electronic MultiBeam Radio Astronomy ConcEpt
EMC.....	Electromagnetic Compatibility
EVLA	Expanded VLA
FAT	Factory Acceptance Test
FCA	Functional Configuration Audit
GLAST	Gamma-ray Large Area Space Telescope
HPC.....	High Performance Computing
IEC	International Electrotechnical Commission
IEEE.....	Institute of Electrical and Electronics Engineers
ICD.....	Interface Control Document
INCOSE	International Council on Systems Engineering
ISO	International Standards Organisation
KAT	Karoo Array Telescope Project
km	Kilometre
LEMP	Logistic Engineering Management Plan
LOFAR.....	Low Frequency Array
LRU	Line Replaceable Unit
LWA.....	Long Wavelength Array
MeerKAT	The precursor array being built on site in the Karoo
MIL-STD.....	Military Standard
NASA	National Aeronautics and Space Administration
NRAO.....	National Radio Astronomy Observatory
OAR	Observation Action Register
OICD	Operator Interface Control Document
PAF	Phased Array Feed
PCA.....	Physical Configuration Audit
PDR.....	Preliminary Design Review
PMP.....	Project Management Plan
PPR.....	Pre-production Review

PrepSKA.....	Preparatory phase for the SKA
PTR	Principal Technical Requirement
QA&S.....	Quality Assurance & Safety
RAM.....	Reliability, Availability and Maintainability
Rev	Revision
RFI	Radio Frequency Interference
RSP	Reference Science Plan
S&R.....	Statutory & Regulatory
SAT	Site Acceptance Test
SEMP	System Engineering Management Plan
SKA	Square Kilometre Array
SKADS.....	SKA Design Studies
SRR	(Sub)System Requirements Review
SRU	(Work)Shop Replaceable Unit
SSEC.....	SKA Science and Engineering Committee
STaN	Signal Transport and Networks
TBC	To be confirmed
TBD	To be determined
TDP	Technology Development Program
TRR	Test Readiness Review
VLA	Very Large Array
WBS.....	Work Breakdown Structure
WBSPF.....	Wide Band Single Pixel Feed
WPC.....	Work Package Consortium
WP2.....	PrepSKA Work package 2
WP3.....	PrepSKA Work Package 3

1 Introduction

1.1 Purpose of the document

The engineering activities of the SKA Observatory development will be conducted in parallel with all levels of the project spread across the globe at many contributing institutions and companies. It is therefore of the utmost importance that a coherent system engineering approach and focus be created early and be maintained throughout the life cycle of the project.

The purpose of this System Engineering Management Plan (SEMP) is therefore to provide the framework and guidance for all engineering activities within the overall SKA project.

1.2 Scope of the document

This System Engineering Management Plan (SEMP) will describe the System Engineering approach, activities, products, processes, tools and controls that will be used during the relevant phases of the project to support and eventually ensure the successful development, deployment and commissioning of the SKA Observatory, including maintenance and support capabilities, on the two selected sites.

Against the background of the proposed 'full' SKA (SKA2), a subset of it has been proposed as a Phase 1 (SKA1). This SEMF equally applies to this first phase programme as it does to the full SKA, and has not been tailored for Phase 1.

This SEMF is a living document and will be updated at regular intervals to reflect changes and progress.

2 REFERENCES

2.1 Applicable documents

The following documents are applicable to the extent stated herein. In the event of conflict between the contents of the applicable documents and this document, the applicable documents shall take precedence.

- [AD1] SKA Project Management Plan (PMP) (to be prepared)
- [AD2] SKA Interface Management Plan SKA-TEL.SE.INTERF-SKO-MP-001
- [AD3] Change Management Procedure SKA-TEL.SE.CONF-SKO-PR-001
- [AD4] SKA Product Assurance & Safety Plan SKA-OFF.PAQA-SKO-QP-001

2.2 Reference documents

The following documents are referenced in this document. In the event of conflict between the contents of the referenced documents and this document, this document shall take precedence:

- [RD1] R.T. Schilizzi et al, 'Project Execution Plan Pre-Construction Phase for the Square Kilometre Array (SKA)', MGT-001.005.005-MP-001, dated 2011-01012
- [RD2] P.E. Dewdney, 'SKA Science-Technology Trade-Off Process', WP2-005.010.030-MP-004, Rev 1.1, dated 2010-01-20.
- [RD3] ISO/IEC 26702 (IEEE Std 1220-2005), 'Systems engineering – Application and management of the systems engineering process', dated 9 September 2005.
- [RD4] ISO/IEC 15288 (IEEE Std 15288-2008) 'Systems and software engineering — System life cycle processes', dated 1 February 2008
- [RD5] NASA SP-2007-6105 Rev1 NASA 'Systems Engineering Handbook' dated December 2007
- [RD6] INCOSE Publications, 'Systems Engineering Handbook – A guide for system life cycle processes and activities', V3.1 dated August 2007.
- [RD7] T. Thurston and W. Davis, 'Gamma-ray large area space telescope (GLAST) - Large area telescope (LAT) - Systems engineering management plan', document number LAT-MD-00066-01, 3rd draft dated 23 January 2001.
- [RD8] K. Cloete, 'PREPSKA Documentation Standards, Handling and Control', document number MGT-040.010.010-MP-001, Rev C, dated 2009-04-02.
- [RD9] D. Liebenberg, 'SKA Logistic Engineering Management Plan (LEMP)', document number WP2-005.010.030-MP-002, Rev C, dated 2010-01-18.
- [RD10] Proposed American National Standard "Guide to the Preparation of Operational Concept Documents" ANSI G-043A-201X
- [RD11] K. Cloete et al., 'Pre-Construction Phase, Stage 1 Work Breakdown Structure and Statement of Work', MGT-001.005.010-WBS-001
- [RD12] SKA Science Case, C. Carilli and S. Rawlings (editors), 'Science with the Square Kilometre Array', New Astronomy Reviews, Vol.48, Elsevier, December 2004
- [RD13] SKA Strategy to Proceed to the next Phase (CoDR doc): WP2-005.010.030-PLA-001
- [RD14] SKA1 Strategy to Proceed to the next Phase (dCoDR doc): WP2-005.010.030-PLA-002
- [RD15] SKA Risk Register (dCoDR doc): MGT-090.010.010-RE-003
- [RD16] SKA Project Dictionary (dCoDR doc): MGT-040.030.015-LST-001
- [RD17] SKA Costing Strategy (dCoDR doc): MGT-040.070.000-MP-001
- [RD18] SKA Science-Technology Trade-Off Process (dCoDR doc): WP2 005.010.030-MP-004
- [RD19] Observing Time Performance Factors in Carrying out SKA Trade-Offs (dCoDR doc): WP2-005.010.030-PR-001
- [RD20] SKA Science Operations Plan (CoDR doc): WP2-001.010.010-PLA-001
- [RD21] SKA Science and Support Operations Plan (dCoDR doc): WP2-001.010.010-PLA-002

-
- [RD22] SKA1 High-level System Description (dCoDR doc): WP2-005.030.010-TD-002
 - [RD23] SKA High-Level System Description (CoDR doc): WP2-005.030.010-TD-001
 - [RD24] SKA strategies and philosophies (dCoDR doc): WP2-005.010.030-TR-001
 - [RD25] SKA Configurations Design (dCoDR doc): WP3-050.020.000-R-002
 - [RD26] Dishes Requirement Specification (CoDR doc): WP2-020.030.020-RS-001
 - [RD27] Concept description and investigations report for Dish a (Canada/US) (CoDR doc): WP2-020.045.010-TD-001
 - [RD28] Concept description and investigations report for Dish b (China) (CoDR doc): WP2-020.045.010-TD-002
 - [RD29] Concept description and investigations report for Dish c (Netherlands) (CoDR doc): WP2-020.045.010-TD-003
 - [RD30] Concept description and investigations report for Dish d (China) (CoDR doc): WP2-020.045.010-TD-004
 - [RD31] Concept description and investigations report for Dish e (RSA) (CoDR doc): WP2-020_045_010-TD-005A
 - [RD32] Concept description and investigations report for Single Pixel Feed Payloads (CoDR doc): WP2-020.050-TD-001
 - [RD33] SPF Receiver requirements specification (CoDR doc): WP2-020.065-RS-001
 - [RD34] SPF Receiver risk register (CoDR doc): WP2-020_065-RE-001-A
 - [RD35] AA Strategy to Proceed to Next Phase (SRR) (CoDR doc): WP2-010.020.010-PLA-001
 - [RD36] AA Concept Descriptions (CoDR doc): WP2-010.020.010-TD-001
 - [RD37] AA System Requirements Specification (CoDR doc): WP2-010.020.010-SRS-001
 - [RD38] AA Implementation (CoDR doc): WP2-010.020.010-TR-001
 - [RD39] AA Risk Register (CoDR doc): WP2-010.020.010-RE-001
 - [RD40] Requirements document for the signal transport and networks domain (CoDR doc): WP2-030.030.000-SRS-002
 - [RD41] STaN high level description (CoDR doc): WP2-030.030.030-TD-001
 - [RD42] STaN strategy to proceed to the next phase (CoDR doc): WP2-030.030.000-PLA-001
 - [RD43] STaN Route to Technology Roadmap (CoDR doc): WP2-030-030-030-PLA-001
 - [RD44] STaN Risk Register (CoDR doc): WP2-030.030.030-RE-001
 - [RD45] Cost & Power summary for sub-system concepts proposed for SKA STaN (CoDR doc): WP2-030.030.030-CR-001
 - [RD46] Concept description of the wideband single pixel feed analogue optical link (CoDR doc): WP2-030.050.010-TD-001
 - [RD47] Antenna network for AA-lo: Concept description (CoDR doc): WP2-030.050.010-TD-002
 - [RD48] Phased array feed STaN concept description for the SKA (CoDR doc): WP2-030.050.010-SSDD-003
 - [RD49] SKA Digital Data Back Haul Concept Design Document (CoDR doc): WP2-030.060.040-SD-001
 - [RD50] Concept description cots digital data back haul for the SKA (CoDR doc): WP2-030.060.010-TD-001
 - [RD51] Network infrastructure concept description (CoDR doc): WP2-030.080.000-TD.001
 - [RD52] Questions to ASKAP precursor test arrays for the STaN CoDR (CoDR doc): WP2-030.030.030-RFI-003
 - [RD53] Questions to KAT7 precursor test arrays for the STaN CoDR (CoDR doc): WP2-030.030.030-RFI-002
 - [RD54] Signal Processing Strategy to Proceed to the Next Phase (CoDR doc): WP2-040.010.030-PLA-001
 - [RD55] Signal Processing CoDR Review Panel report: WP2-040.020.011-R-001
 - [RD56] Signal Processing Reply to CoDR Panel Report: WP2-040.020.011-R-002
 - [RD57] Signal Processing Technology Roadmap (CoDR doc): WP2-040.030.011.TD-001

-
- [RD58] Signal Processing System Requirements (CoDR doc) WP2-040.030.000.SRS-001
 - [RD59] Signal Processing High Level Description (CoDR doc): WP2-040.030.010-TD-001
 - [RD60] ASKAP Style SKA2 Correlator Concept Description (CoDR doc): WP2-040.060.010-TD-001
 - [RD61] SKA Phase 1 Correlator and Tied Array Beamformer (CoDR doc): WP2-040.060.010-TD-002
 - [RD62] ASKAP Style SKA2 Correlator Concept Description (CoDR doc): WP2-040.060.010-TD-001
 - [RD63] SKA Phase 1 Correlator and Tied Array Beamformer (CoDR doc): WP2-040.060.010-TD-002
 - [RD64] A UNIBOARD-Based Phase 1 SKA Correlator And Beamformer Concept Description (CoDR doc): WP2-040.070.010-TD-001
 - [RD65] SKA CASPER Correlator Concept Description (CoDR doc): WP2-040.080.010-TD-001
 - [RD66] Software Correlator Concept Description (CoDR doc): WP2-040.040.010-TD-001
 - [RD67] Software Correlator Concept Description (CoDR doc): WP2-040.040.010-TD-002
 - [RD68] Signal Processing Risk Register (CoDR doc): WP2.040.010.010.RE-001.
 - [RD69] Pulsar Survey with SKA Phase 1 (CoDR doc): WP2-040.030.010-TD-003
 - [RD70] Searching for Fast Transients (CoDR doc): WP2-040.030.010-TD-002
 - [RD71] Signal Processing CoDR concepts (CoDR doc): WP2-040.030.010-TD-003
 - [RD72] Signal Processing Strategy to Proceed to the Next Phase (CoDR doc): WP2-040.010.030.PLA-001
 - [RD73] Context of the Software and Computing CoDR (CoDR doc): WP2-050.020.010-PLA-002
 - [RD74] SW&C Requirements Specification (CoDR doc): WP2-050.020.010-SRS-001
 - [RD75] Analysis of requirements derived from the Design Reference Mission (CoDR doc): WP2-050.020.010-RR-001
 - [RD76] Software and Computing System Overview (CoDR doc): WP2-050.020.010-DD-001
 - [RD77] SW&C: Visibility Processing (CoDR doc): WP2-050.020.010-SR-001
 - [RD78] SW&C: Processing for Pulsars and Transients (CoDR doc): WP2-050.020.010-SR-002
 - [RD79] The CyberSKA platform for data intensive radio astronomy (CoDR doc): WP2-050.020.010-SR-003
 - [RD80] HPC Technology Roadmap (CoDR doc): WP2-050.020.010-SR-004
 - [RD81] Software and Computing Risk Register (CoDR doc): WP2-050.020.010-RE-001
 - [RD82] Software Engineering (CoDR doc): WP2-050.020.010-MP-001
 - [RD83] SW&C Strategy to Proceed to the Next Phase (CoDR doc): WP2-050.020.010-MP-002
 - [RD84] SKA Monitoring and Control Strategy (dCoDR doc): WP2-005.065.000-R-002
 - [RD85] Monitoring and Control High Level Description (CoDR doc): WP2-005.065.020-TD-001
 - [RD86] Monitoring and Control Element Level Requirements (CoDR doc): WP2-005.065.020-SRS-001
 - [RD87] Monitoring and Control Design Concept Descriptions (CoDR doc): WP2-005.065.020-TD-002
 - [RD88] Monitoring and Control Element Level Risk Register (CoDR doc): WP2-005.065.020-RE-001
 - [RD89] Monitoring and Control Strategy to Proceed to the Next Phase (CoDR doc): WP2-005.065.020-PLA-002
 - [RD90] Concept description for synchronisation & timing for the SKA (CoDR doc): WP2-030.070.000-TD-001
 - [RD91] AA-mid System Requirements Specification (dCoDR doc): WP2-015.020.010-SRS-001
 - [RD92] AA-mid Concept Descriptions (dCoDR doc): WP2-015.020.010-TD-001
 - [RD93] AA-mid Strategy to Proceed to Next Phase (dCoDR doc): WP2-015.020.010-PLA-002
 - [RD94] AAVS-mid Project Plan (dCoDR doc): WP2-015.020.010-PLA-003
 - [RD95] AA-mid Analogues Power and Cost Analysis (dCoDR doc): WP2-015.020.010-TR-001
 - [RD96] AA-mid Risk Register (dCoDR doc): WP2-015.020.010-RE-001

- [RD97] Phased Array Feed requirements document and concept description for the PAF sub system (CoDR doc): WP2-025.030-RS-001 and WP2-025.030-TD-001
- [RD98] Concept description and investigations report for PAF feed payload (CoDR doc): WP2-025.035-TD-001
- [RD99] Concept descriptions and investigations reports for PAF receiver options (CoDR doc): WP2-025.050-TD-003, WP2-025.050-TD-002 and WP2-025.050-TD-001
- [RD100] Risk register for PAFs (CoDR doc): WP2-025.030-RE-001
- [RD101] Technology road map for PAFs (CoDR doc): WP2-025.030-TD-003
- [RD102] Software description for PAFs (CoDR doc): WP2-025.050-SD-001
- [RD103] PAF logistic engineering plan (CoDR doc): WP2-025.030-MP-001
- [RD104] PAF initial cost estimates (CoDR doc): WP2-025.030-TD-002
- [RD105] PAF plans for the next phase (CoDR doc): WP2-025.030-PLA-001
- [RD106] SKA1 System Baseline Design SKA-TEL-SKO-DD-001

3 Introduction

A reference high level SKA design has been established [RD106]. As presented the SKA will not only consist of two sites, with very many Elements and Sub-elements, it will be physically spread out across thousands of kilometres on the selected sites and even across the globe. Furthermore, there will be some degree of integration with the Precursor projects, large radio-observatories being developed on the respective sites, and the development will take place with the presence of other telescopes and experiments on the sites. These aspects together with the fact that the development work is also distributed internationally makes the adoption of a coherent system engineering approach in the project critical to its success. It is in this context that this Systems Engineering Management Plan (SEMP) has been developed and refined over the past several years.

3.1 System Engineering in the context of the SKA

It is foreseen that during the SKA development process several iterations between science definition work and engineering effort will take place and that other important inputs to the overall system design such as the operations, support and environmental studies, will be developed, refined and brought into the design effort.

For a project as large and complex as the SKA, the adoption and execution of a systems engineering approach is mandatory. Examples are spread throughout industry, military and large research facility projects where the systems engineering approach has been adopted and is being used to great advantage.

The System Engineering approach elaborated in this document is already adopted and assumed in the Project Execution Plan [RD1] and the SKA Business Plan.

System Engineering is defined as follows:

Systems engineering is the art and science of developing an operable system capable of meeting requirements within often opposed constraints. Systems engineering is a holistic, integrative discipline, wherein the contributions of structural engineers, electrical engineers, mechanism designers, power engineers, human factors engineers, and many more disciplines are evaluated and balanced, one against another, to produce a coherent whole that is not dominated by the perspective of a single discipline. (Extract from NASA Systems Engineering Handbook, NASA/SP-2007-6105, Rev1)

Systems engineering is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system. (Extract from INCOSE Systems Engineering Handbook, Rev 3.1)

In summary it can be said that systems engineering is a balanced and iterative approach aimed at the eventual successful realisation and operation of systems by ensuring the inclusion of the full spectrum of requirements and engineering disciplines and with a continuous view of the total life cycle of the system.

With all of this in mind and taking into account that the SKA is a highly complex, large and very distributed project (in terms of institutions and work being performed), the successful adoption and roll out of a systems engineering approach within the project is of critical importance. The process will not only attempt to have the upfront work done very well, it will guide and control the work to be done during subsequent phases at all the levels of the project.

3.2 Project Phases and Transitions

The SKA project has been subdivided into various high level phases namely the Preparatory Phase, the Pre-Construction Phase, SKA1 Construction, SKA1 Operations (with SKA2 Construction in parallel)

and SKA2 Operations. The transitions between the phases will overlap with the next phase starting before the preceding phase has been completed. This is important because, for each phase of the project, the systems engineering process activities and requirements differ. Work will therefore be conducted concurrently as the phases overlap, and good management and control of these activities will be essential.

The relationship between SKA high level Project phases, SKA System Engineering phases and ISO 26702 [RD3] is shown in figure 1.

The primary development and construction phases of the project are split into Phase 1 and Phase 2, known as SKA1 and SKA2. They serve to reduce overall development risk: Phase 1 will serve as a final confirmation of a production baseline for key areas of the project before the much larger roll-out of equipment in Phase 2 commences. Phase 2 can therefore be seen as a continuation of Phase 1 but at an escalated rate of production. Phase 2 will, however, be different in two key areas. The first being the fact that the rate of roll-out of equipment on site will escalate with resulting increase in installation, acceptance, integration, commissioning and support requirements. Throughout the development this escalation will be taken into account and will drive some of the system requirements. The necessary outputs will include plans, activities and costs for evolving the project from Phase 1 to Phase 2 and will include aspects such as acceleration in the production of hardware, the increase in personnel both on site and off site, scaling up and expansion of infrastructure etc. The second difference between Phase 1 and Phase 2 is the fact that the Phase 1 instrument will be utilised for early science work while the construction of Phase 2 will be continuing around it. Clear plans, strategies and processes will be developed during the development activities to ensure that the requirements for this transitioning are well thought through and form part of the eventual design of the system, especially that of Phase 1.

Phase 2 (and perhaps Phase 1 if maturity can be demonstrated – see section 7) allows for the incorporation of certain technologies currently being developed in the framework known as the Advanced Instrumentation Programme (AIP). The impact of AIP technologies are studied during the SKA definition work in order to be ready as and when incorporation decisions are made (conventionally at PDR – see below).

The above considerations result in a need to capture, maintain and analyse a set of traceable requirements, known as Build-out and Evolution requirements, whose effects will be felt throughout the development of SKA1.

The need to consider the partial or full integration of the Precursors at each site will be dealt with in a similar way; through the drafting of specific requirements.

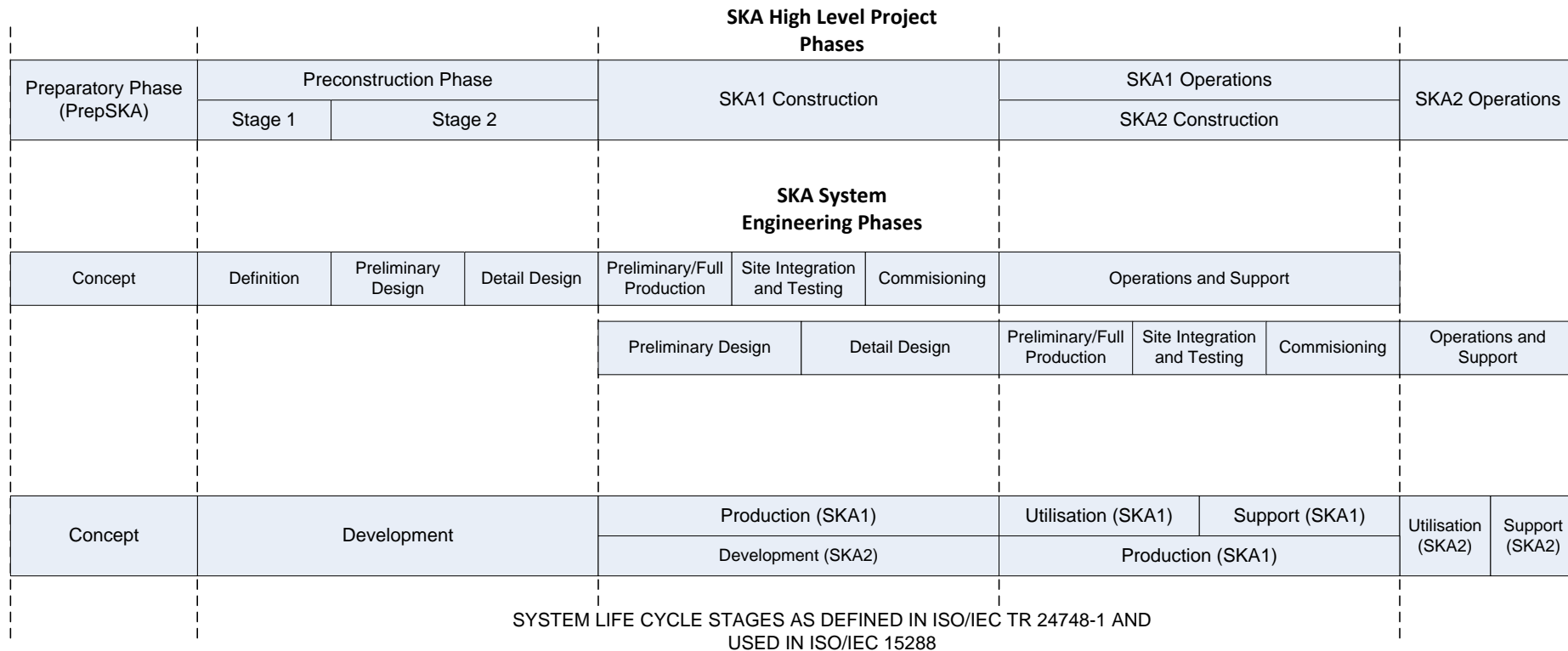


Figure 1: The temporal correspondence between SKA Project and SKA System Engineering phasing compared to industrial standard phasing. Note the splitting of the Preconstruction Phase into 2 Stages, with Stage 1 ending at the final Element level Requirements Review.

3.3 General System Engineering Philosophy

3.3.1 Development Approach

Because the SKA will be a combination of very complex technologies of which many are maturing (as evidenced by the Domain Concept Design Review documentation - [RD26] to [RD105]), the development risks that the project is facing are high. A rigorous single pass top down system engineering philosophy will therefore not deliver the optimum solution and an eventual successful implementation and roll out of the SKA system. The model that has been adopted leans more towards a concurrent development whereby requirements and potential solutions and designs are developed in parallel with frequent cross co-ordination and back - referral.

From the top level, iterations and trade-offs will be strongly linked to the science requirements and to cost. The underlying theme for the sequence of all the design reviews is to create a system design for the full SKA, with well-understood cost, commensurate with maximizing science return. Top-level Observatory performance and functionality requirements are captured in the Design Reference Mission documents, one for each of Phases 1 and 2. These case studies have been selected to form an “envelope” of science requirements

Because of the iterative nature of the development, the work to be done will include refinement of technologies and requirements below the system level, which will provide feedback and inputs to the Element and System levels of the project. These inputs from the lower levels will also be utilised in the trade off studies and eventual refinement of the System level specifications and design. The fact that the system engineering process is concurrent at a number of levels will provide numerous challenges and potential pitfalls. Discipline will have to be maintained throughout the process in terms of documentation development, reviews, standards, quality, traceability and the other requirements as set out in this Plan. This will be applicable to hardware as well as software developments.

3.3.2 Requirements Engineering

The combination of the DRM and the science operations chapters of the ConOps form the basis of the science (functional) requirements for SKA.

The SKA is structured hierarchically into a number of levels, of increasing detail as one descends (see 4.4). The most important level, just below Telescope level, is Element level.

Requirements will flow down and be allocated to partitions of the SKA which have been derived through the study of requirements. In order that the complex work of scoping, scaling and analysing of Elements of the SKA can start as soon as possible, the process allows for so-called Look-Ahead requirements analysis (see 5.2.3.2) where ‘Elements’ have been proposed. These initial customary partitions of an archetypal radio observatory, plus predetermined receptor types assumed during the Preparatory Phase of SKA1, are:

- Dish Array
- Low Frequency Aperture Array
- Central Signal Processing
- Science Data Processing
- Telescope Manager
- Signal and Data Transport & Synchronisation and Timing
- Infrastructure & Power

These Elements are only defined to a limited extent at the commencement of the Pre-Construction Phase, and the boundaries and interfaces between them are largely undefined. The Requirements Engineering work will refine them based on on-going design work.

The non-functional requirements will be derived from the baseline reference design [RD106].

4 System Engineering Process Planning

4.1 SKA Organisation Responsibilities and Relationships

The Office of the SKA Organisation ('SKA Office') contains System Engineering functions operating at the higher levels of the Project [AD1]. They are made up of two subgroups. These subgroups are:

- System Engineers dedicated to the design, integration and verification of the System as a whole. These engineers also have responsibility for the System wide, low risk development, design and operations aspects. These engineers will be led by the Chief System Engineer.
- Element System Engineers who specialise in the systems aspects of the major partitions of the SKA and have specialised domain expertise to enable them to oversee the mixture of high and low risk developments. They will ensure that inputs from the relevant lead and supporting institutions flow into the overall system engineering effort.

This System Engineering group as a whole is responsible for the development of the system according to the principles outlined in this document. It develops, supports, and operates the processes described later.

4.2 Integration of the global System Engineering Effort

The global effort associated with the development of the SKA outside the SKA Office has been divided into the four categories [RD1] and listed below:

- Element Work Package Consortia: these consortia are tasked with the work to develop the Elements and participate in system level integrative effort where required
- Precursor: Telescopes on each of the two sites; namely ASKAP and MeerKAT.
- Design Study (Verification Programme): A study of one or more major sub-systems of the SKA design, including the construction of prototypes and includes the TDP and AAVP.
- Pathfinder: SKA-related technology, science and operations activity and includes e-MERLIN, LOFAR, EMBRACE, APERTIF, and MWA.

The former two are directly related to the Project, and the latter two are associated or relevant projects used for learning.

Under the leadership of the SKA Office, system engineering inputs from the consortia will be combined into the system. The presence of specialists from this list is to ensure appropriate expertise is available for the main focus of the combined System Engineering work, namely the design aspects of the SKA at system level.

The work carried out by the WPCs will be within a specific frame work adapted to the products being developed. This requires some tailoring of the System Engineering process – see section 5.1.

4.3 Verification Programmes

The SKA programme has on-going development demonstration programmes referred to as 'Verification Programmes'. These projects are intended to accelerate the development of a series of prototypes converging on the respective SKA design through real-world developments and trials.

4.4 System Breakdown

The hierarchy is a first step in the establishment of the system view of the project and is intended to provide a clear and coherent view on the scope and composition of each of the building blocks and of the system as a whole. It is used in the 'Product' components of a Work Breakdown Structure, thus rendering the associated work as hierarchical also. Many of the development steps proceed hierarchically.

An example of the members of a typical hierarchy are shown in Table 1.

The hierarchy will also facilitate better communication and understanding and assists in the alignment of terminology throughout. It provides a clear view of where requirements for each of the blocks originate and illustrates the flow down of the process.

Product hierarchy is an expression of architecture, and is to be derived at all levels from an analysis of requirements and constraints.

Some of the implications of the hierarchy are:

- Documentation will be developed for each of the building blocks within the hierarchy. For example - a Requirement Specification for the dishes Element will be developed. This Requirement Specification will receive its inputs from the telescope system and will in turn allocate requirements to its major Sub-elements which in this example are the structure, feeds and LNAs, receivers, local monitoring and control and local infrastructure.
- Requirements traceability will follow the links between the building blocks and levels. For example the requirements for the aperture array will trace its requirements to the telescope which in turn will trace its requirements to the System.
- The hierarchy also serves as a definition of responsibilities. Each building block has to be allocated to an organisation which will be responsible to ensure that the systems engineering work within that building block is being carried out in accordance with this Plan.

It will be possible to add, remove or combine building blocks at any of the levels. However, there are various aspects that will need to be considered before this is done.

The hierarchy as shown is not intended to be the final version and is provided as reference only. It is important to develop and agree on the hierarchy very early on in the project because not only will it will guide the system engineering effort of the project as a whole, it will form the basis for the system engineering work and products to be delivered at each level.

Table 1. An example of a vertical slice through the hierarchy of products

Level	Product Entity
L1 Observatory	SKA
L2 System	Telescope
L3 Element	Synchronisation & Timing
L4 Sub-element	Station Frequency Reference (Equipment)
L5 Assembly	Frequency Distribution Rack (Equipment)

L6	Frequency Transmitter
L7	Laser
L8	Drive electronics
L9	Temperature control (electronics)
L10 Part	AD590 temperature sensor

The example provided by Table 1 has 10 Levels. It is expected that other slices will have more or less Levels. For this reason Tiers L6 and below are not given natural language names, as some branches reach Part level at a higher Level than others.

Aspects that will need to be considered during the partitioning of the system include a view on how functions will be provided when any of the blocks are taken away and how the eventual testing and acceptance will be conducted. For example – if it is foreseen that the dish Element will be tested and accepted separately from other Elements, it will be necessary to firstly have a dish Element and to develop a requirement specification for this Element against which eventual testing and acceptance will be performed.

4.5 Major Deliverables

The eventual aim of the project is to deliver a cost effective, fully operational and fully supportable SKA Observatory. In support of this aim the deliverables for each of the various high level Project phases will vary, as described below.

4.5.1 Pre-Construction Phase

The Pre-Construction Phase will be divided into two stages, namely Stage 1 – leading to the conclusion of all Element Requirements Reviews, and Stage 2 – the preliminary and detail design activities ending in the System level Critical Design Review.

4.5.1.1 System Engineering Documentation – Stage 1

The complete list of documentation to be developed will not be listed here. However, a core list applicable at Element level, their relationships and their outline contents are given in Appendices 1 and 2. Some high level guidance on the technical documentation can be found as part of the description of each of the technical reviews, before which they are delivered. Details will be expanded during normal work and documents and document types will be refined. In general it can be stated that the documentation will include:

- A baselined Design Reference Mission (DRM) – Phase 1
- A baselined Design Reference Mission (DRM) – Phase 2
- A baselined Concept of Operations (ConOps) – covering both Phases 1 & 2
- A baselined Build-Out and Evolution Requirements document
- Requirements specifications for the System
- An Architectural Design document (ADD) for the System
- A Verification Plan for the System
- Requirement specifications for all Elements of the System
- Architectural Designs for all Elements of the system including software
- Requirements specifications for all Sub-Elements
- Architectural Designs for all Sub-Elements
- A draft Logistics Engineering Management Plan (LEMP)
- A draft Integrated Logistics Support Plan
- Interface control definitions and interface designs at all levels
- Results of the tests performed on the verification models
- Scaling analysis (where applicable)
- Deployment plan (TBD)
- Upgrade Plan (TBD)
- Fully costed user system breakdown

The results from the studies, trade-offs and analyses etc. of the development activities, will be utilised to support decisions regarding requirements development and design. The models, documents, reports, technical memos and other information ('artefacts') developed and gathered as part of this process will be collected and recorded in a design database. This design database will be managed at all levels and the main custodians of this database will be the SKA Office System

Engineers who will ensure that the source work is correctly and completely generated, it is input to the database, it is controlled and kept up to date.

A design database ensures that each decision is traceable and has a rational basis. Furthermore, the traceability will allow impact analysis to be carried out on change proposals.

The exact implementation of this database is to be determined at the start of the Pre-construction Phase.

The documenting of the SKA will not only underpin the costed user system design but will form the basis for the rest of the project. As a consequence, the documentation and other artefacts must be of high quality, complete and coherent. To achieve this goal, a number of supporting measures will be put into place including the establishment and utilisation of a repository of artefacts and the establishment of baselines for each of the building blocks of the SKA. Each of these aspects is described in more detail in later paragraphs. It is furthermore proposed that a number of templates be created by the SKA Office to be utilised throughout the project.

4.5.1.2 *Repository*¹

A central repository for the project will be established and maintained by the SKA Office. All artefacts developed specifically for the SKA will be submitted to this repository. It is furthermore proposed that all supporting documentation collected also be captured within the repository.

Documentation handling guidelines and procedures have been developed by the SKA Office to guide activities in this regard [RD8].

It will be the responsibility of the SKA Office Element System Engineers (or WPC system engineers in cases where SKA Office is not taking the lead) to ensure that the documentation developed within their Element is change controlled and is submitted to the repository on a regular basis, especially before and after baseline reviews.

4.5.1.3 *Engineering Baselines*

A Baseline is an agreed set of definitions, requirements, procedures, rules, etc. that are universal across the Project and is held stable against change to allow time for a complete analysis of their impact on the design, development and operation of the System. A Baseline is formally established following formal review.

The evolution of each of the building blocks of the SKA will be defined in a series of baselines and baseline (technical) reviews (see paragraph 5.3.1).

These baselines will progress from a high level down to the lower levels but the degree to which this formality will recur will vary from Element to Element. However, following the establishment of a baseline at any hierarchical level the documentation will be 'frozen' for the particular baseline and changes thereafter will be controlled.

To be able to successfully achieve an engineering baseline, all the documentation as specified in this SEMP² will have to be presented during the review, reviewed, updated and submitted to the central repository.

¹ Note that the word repository will be used throughout this document. It is, however, recognised that a comprehensive Configuration Management System, Document Management System and related Configuration Management Plan will be implemented within the project (also see paragraph 6.8).

² It will be possible to combine documents or to omit documents from a baseline review. However, these changes will be motivated and be approved before the relevant review is conducted.

4.6 Engineering Standards and Procedures

For the development of this document, four international system engineering standards were utilised as guidelines ([RD3][RD4][RD5][RD6]) as well as the Gamma-ray Large Area Space Telescope SEMP [RD7]. Although not prescribed for the SKA, it is highly recommended that the international standards be read by all because they provide a very good view of the systems engineering process for large projects.

During the course of the development the utilisation of other international standards and their applicability to the SKA will be investigated. Examples are:

- Risk management (IEEE 1540)
- Quality management (ISO 9001)
- Logistics and support (DEF_STD_060, MIL-STD-1388-2B and MIL-STD-1629A).
- Health and Safety (MIL-STD-882D, IEC 62061, IEC 61511 and various others)
- Electronic publications (AECMA 1000D)

If found to be applicable and required, the standards will be introduced and made mandatory for the project by the writing of requirements to that effect.

The standards thus made applicable, and others thought useful for reference, will also be listed in an Applicable & Reference Standards document.

Although not an exhaustive list it is foreseen that the following aspects may be included:

- Monitoring and Control
- Self-generated Radio Frequency Interference mitigation
- Built in Testing (BIT)
- Timing and synchronisation
- Logistic engineering standards and procedures
- Environmental standards
- Units of measure standards

4.7 Constraints

Constraints are analogous to requirements, and are introduced and changed using similar processes, with the exception that a full rationale may not be available. Approval at an appropriate level is of course mandatory.

5 System Engineering Process and Application

5.1 Tailoring

Work packages may tailor their system engineering process. The project office will require visibility into the system engineering processes and evidence of the implementation of a robust system engineering process.

5.2 System Engineering Process

The system engineering process as defined in [RD3] and [RD6] is shown graphically in Figure 2 and this process is adopted and applied within the SKA project office. In general each of the activities shown in Figure 2 ought to be conducted at each of the levels of the hierarchy and during the

specific phases of the project as the project moves through its lifecycle. As seen from the figure the activities are iterative and are being managed through a change Control Process.

Descriptions of the steps of the system engineering process are given below. A summary is:

- User needs are collected. Users include operators, maintainers, resource managers, etc. as well as the beneficiaries of the products, i.e. scientists.
- Constraints and other design drivers are collected, such as proposed operational concepts, needs for expansion, governmental regulations, good engineering practice, re-use of existing infrastructure, etc.
- Formal Requirements are drafted based on analyses of the design drivers.
- Formal requirements are analysed as a whole and validated against user needs, constraints, etc.
- The range of solutions is identified and data collected regarding characteristic performance, functionality and cost.
- Functional analysis is carried out whereby the principal functions are identified and the interactions between them described and verified.
- Requirements allocation to lower level architectures is developed and carried out.
- Design verification by the exercise of appropriate models (verification by analysis)
- Iteration is carried out where requirements cannot be met by any available solution or combination of solutions.
- The specification of solutions is determined by detailed design and verification.
- The system engineering process concludes with definitive verification of the as built system at the necessary stages of physical integration.

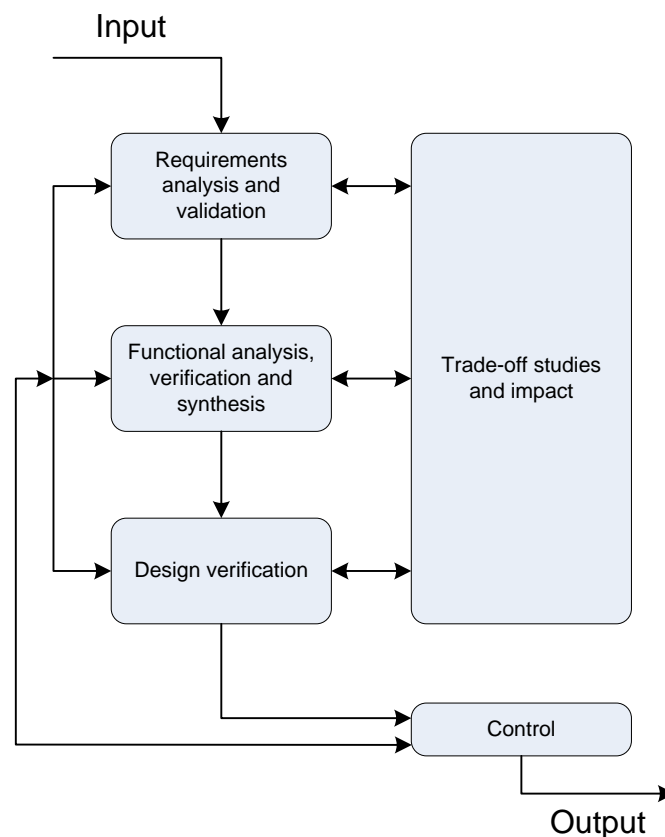


Figure 2: The systems engineering process.

5.2.1 User needs

As an initial reference, the user needs for the SKA user system are being captured in the Design Reference Mission documents and in the Concept of Operations.

At each level of the hierarchy the user needs will have to be identified and formalised.

5.2.2 Requirements drafting

5.2.2.1 Overview

In the perspective of the SKA Office – Work Package Consortium (WPC) relationship, these requirements are transferred by the SKA Office to the WPC for the production of lower level specifications. .

5.2.3 Requirements Analysis and Validation

5.2.3.1 Principal Process

Understanding the requirements and making sure they are complete and stable are two of the most important aspects of the system engineering process because the rest of the activities are all based and derived from the requirements being developed during this initial step.

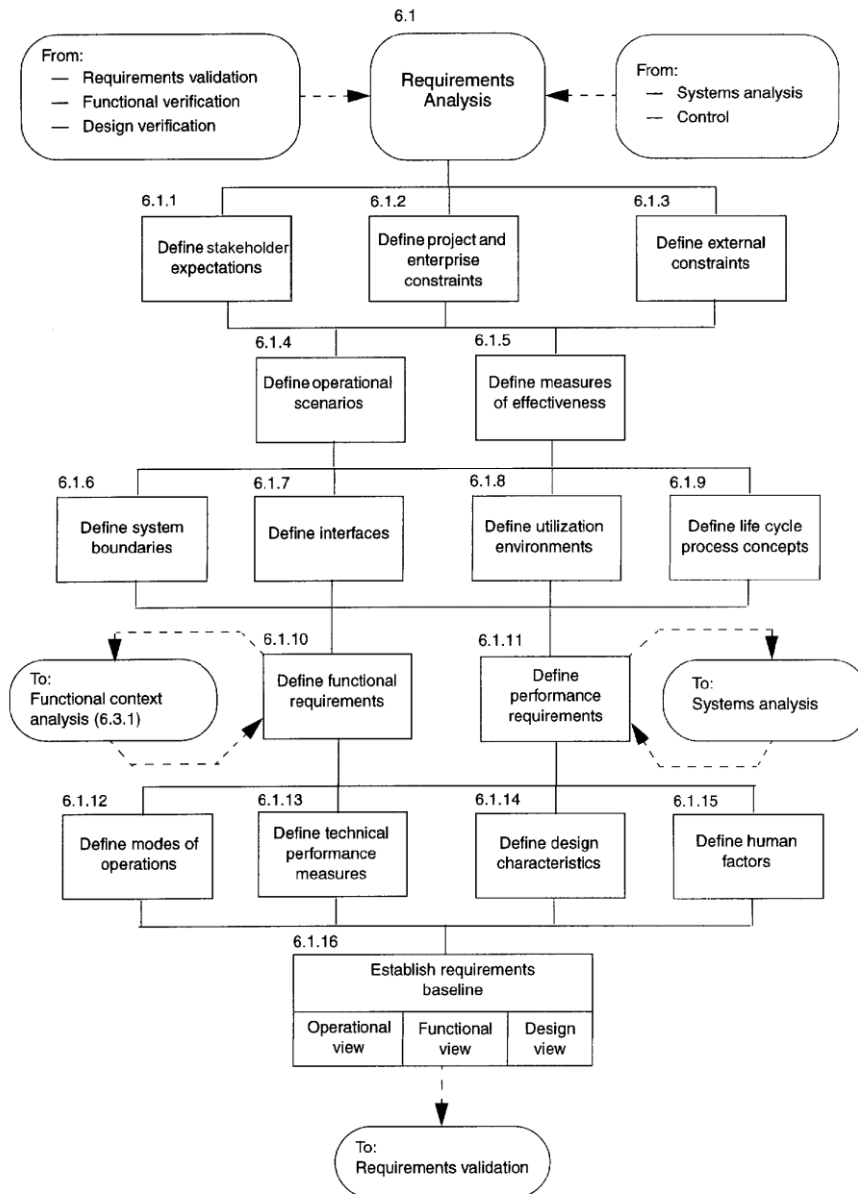


Figure 3: Requirements analysis process..

The baseline reference design is the primary source for the requirement gathering and analysis and includes, amongst others, the outputs from PREPSKA WP2, WP3, Task Force activities, Working Group activities, interaction with manufacturers and industry, interaction with other radio and optical telescopes, etc.

A subset of requirements has been allocated to each programme as a starting point based on the baseline reference design. These requirements will not be on a firm basis until the first iteration with the consortia has taken place. Thus risk is being carried between the initial requirements and the final requirements as drivers of Elements and sub-elements. As the requirements on user system level mature these requirements will be flowed down and it is proposed that the status and impact of requirements be discussed during each review and progress meeting.

The process is iterative and as the verification programmes and precursor design studies and other pathfinder projects move forward they will provide feedback towards the system specifications.

Requirements validation is the process whereby the requirements that have been developed are validated against the original stakeholder expectations, user needs and project constraints. The process will furthermore focus on the identification of gaps and to determine and confirm that the full spectrum of inputs has been taken into account and that the system will indeed be able to fulfil its full life cycle requirements.

The techniques that will be utilised for requirements validation include formal technical reviews, peer reviews, work group reviews, scenario studies, simulations and the building and testing of prototypes and verification models.

5.2.3.2 'Look Ahead' Process

The analysis shall take place against the baseline reference design top level architecture.

The analysis provides the following:

- Proposals and rationales for principal technical requirements traceable to science objectives through the DRM, and to other published requirements and constraints (Parent Documents and others). Examples of principal technical requirements are the number of dishes and their size.
- Proposed values/functions for each principal technical requirement synthesised from, and traceable to, proto-requirements.
- Proposed and elaborated verification methods for each principal technical requirement
- A set of constraints and assumptions traceable, to the maximum extent possible, to parent documents. Where such traceability is not possible, full justification shall be given.
- Preliminary identification of which Elements of the reference architecture will contribute to the fulfilment of each principal technical requirement as a first step to allocation.

These analysis reports and technical notes can be used for preliminary trade studies, but are not a substitute for the necessary analyses of the system requirements specification, baselined at SRR.

5.2.4 Functional Analysis, Functional Verification and Synthesis

Functional analysis describes the problem defined by the requirements in more detail and allocates functions and related performance to lower levels of the design.

The end result of this process will be a functional architecture.

Synthesis is the process whereby the functional architecture and elements and Sub-elements are identified. It is during this process that the preliminary design will play a role in the final definition of the system (or element or sub-element). Other aspects such as the utilisation of off-the-shelf equipment and standardisation will also be addressed during this process.

The functional analysis, verification and the allocation of these functions to the various Elements and Sub-elements needs to be done to ensure that there are no gaps and that the Elements and Sub-elements are able to perform the functions they are allocated.

Once again this part of the system engineering process will be iterative as requirements mature, design verifications are carried out, results from the verification programmes become available, and feedback from the precursor, design studies and other pathfinders are obtained. The process will be followed to the various levels and will be cascaded down to the lower levels of the SKA design.

5.2.5 Design Verification

As indicated in [RD7] design verification ‘uses trade studies to support decisions about requirements selections and design alternatives’.

To be able to eventually arrive at a final design for the SKA user system the process of design verification will be very important. It will be during this process that all the design options are evaluated and verified against a number of criteria. This part of the system engineering process will primarily be accomplished through trade-off studies.

Trade-offs will be performed at all levels of the project and against a variety of criteria, with cost being the most dominant criterion. However, care must be exercised when performing cost trade-offs because it will be important to ensure that like-for-like trade-offs be done. For instance, all aspects of the life cycle are to be included in the cost before using it as a parameter in trade-offs. Aspects such as development costs, construction costs, operations cost (e.g. staff, power), support costs (e.g. staff, equipment, spares) must always be considered and in some cases it might be more cost effective to invest in a more sustainable design to gain significant benefit during operations.

The studies will not be limited to cost only, and aspects such as technology maturity, reliability, power consumption and many others will also play a role.

It will obviously be important to establish a good cost basis early on in the project and iterate the costs as various design solutions at the various levels are investigated and better data is fed back. To accomplish this, the SKA baseline design will be used. In this regard a number of studies and analyses have already been conducted [RD26] - [RD105] and the results and data from these studies will be consolidated.

The aim of all the studies will be to make choices and decisions based on substantial evidence. For the majority of the cases, the choices will be straight forward. However, a few major decisions will have to be made, especially on System level, in which large elements or sub-elements will be involved. Decisions in these cases will not be simple because of the multi dimensionality of the problem and for these major decisions a sound decision making process has been developed [RD2].

Whenever commercial off the shelf (COTS) equipment is being considered in a design application it must comply with the requirements placed on the applicable element/Sub-element. In particular the environment and interfaces of the actual application must be taken into consideration. The outcome may be that COTS equipment has to be modified before it can be used in the project. Modified COTS hardware and software will be treated in the same way as dedicated SKA developments and will require appropriate verification.

The results and decisions of trade-offs will be documented and reviewed as part of the design traceability effort.

5.3 Application of the System Engineering Process

The high level life cycle phases that will be adopted for the SKA pre-construction project are Conceptual design, preliminary design and critical design. Although the phases are shown sequentially they will overlap with the next phase starting before the preceding phase has been completed. This approach facilitates iterations taking place between activities at various levels of the project, and is in line with the iterative nature of the system engineering process.

In general, a design review will be conducted and a baseline established at the end of each phase.

=

5.3.1 Systems Engineering Phases and Engineering Baselines of the SKA

The paragraphs below are aimed at providing high level guidance on the content and intent of each of the phases and details of the reviews to be conducted at the end of each phase are provided in paragraph 6.5.

Reviews are the formal conclusion of a development phase, signifying readiness to enter the following phase where the cost of decisions will increase. The entry criteria, the deliverables and the success criteria are yet to be fully elaborated, and this will take place during Stage 1.

Engineering baselines will be achieved once the relevant design review has successfully been completed. A baseline is therefore a full set of documents and other artefacts describing the system/element/Sub-element and not just a single document. References to 'baseline designs' should always be put into the context of the system engineering phases and applicable baselines.

5.3.1.1 Concept Phase (completed)

At each level of the project, the system engineering process will be initiated by conducting background investigations into, amongst others, the particular technologies being utilised, technology trends, technology options, work already done and being done by precursors, design studies and other pathfinder arrays and results obtained from this work. Preliminary investigations into the full set of requirements, the interfaces and the risks will also be conducted.

An example of these investigations is to be found at the user system level where numerous studies have been conducted into various technologies, configurations, science options, operations, infrastructure and many more. The results of these investigations culminated in the development of the concepts as captured in the Domain and System Conceptual Design Reviews [RD13] - [RD105]. A solid base has therefore been established and work can now continue into the definition phase.

The concept phase was therefore aimed at investigating and developing a very good understanding of the problem, the questions and risks that will be faced during the next phases of the project and the development of draft high level concept(s) for the system, element or Sub-element (as applicable).

The concept phase was concluded by the series of Conceptual Design Reviews (CoDRs [RD26] - [RD105]). The Concept Baseline was reached upon conclusion of all of the CoDRs.

5.3.1.2 Definition Phase & preliminary design

The aim of the definition phase is primarily to perform requirements analysis and validation to ensure that the complete set of requirements is present and is understood. Gaps will be identified and actions to address these shortcomings will be initiated. The result of these activities will be captured in the relevant Requirement Specifications to be reviewed at the conclusion of this phase.

In support the technology option(s), as confirmed during the CoDR, will be investigated in more detail. Further prototyping and testing may be done and analyses and simulation work will continue.

Modelling takes a key role in this Phase, for architecture, relationships (particularly requirements allocation), parametrics and trade studies.

Trade-off studies between the possible solutions will be performed with the aim of identification and selection of a preferred solution. The trade-offs will include aspects and inputs from the levels above and below.

It is recognised that for some elements or Sub-elements it may not be possible to arrive at a preferred solution during this phase and that more than one solution might be carried forward to the next phase.

Architectural design activities have been initiated producing a first draft Preliminary Design Document at the end of the phase. This establishes the allocation of functions to Elements.

Interfaces will be established and finalised.

During this phase the candidate technical solution(s) selected at the end of the definition phase will be refined and preliminary designs drafted. Functional analysis, validation and synthesis will be performed. Functions will be mapped to configuration items and where possible, final prototypes will be built and tested to confirm the design and the requirements (such as the conclusion of the dish and aperture array verification programmes).

The majority of risks will be retired during this phase and remaining risks will be supported by well thought through and realistic mitigation plans.

The results and underpinning documents generated at element and Sub-element levels will form the base for the finalisation of the system preliminary design phase. This is not the same sequence as for Requirements Reviews, where lower level reviews typically follow after the conclusion of similar reviews at higher level. To ensure that the user system level reaches the optimum maturity level, the process is being reversed for design phases. The overall sequence requires especial stability and completeness of requirements at the system level, and this need will be a major consideration for System level SRR. In the event that any changes are introduced at Observatory level during the final stages of its preliminary design phase, these changes will be cascaded down to the lower levels during the initial stages of the production engineering and tooling phase of the project.

The aim should be to narrow down the options to one low risk baseline technology option (in each functional area) to be confirmed at PDR. Carrying more than one option beyond this point will increase risk to SKA1, will duplicate work (to perform detailed designs on more than one option) and will complicate the Observatory design in its attempt to accommodate more than one option.

This phase will be concluded by the System and Element Requirements Reviews (SRR) and the System Preliminary Design Review (PDR) which follows the individual Element PDRs. The Allocated Baseline is reached upon conclusion of the PDR.

5.3.1.3 Detailed Design Phase

During this phase the designs developed during the preliminary design phase will be refined for aspects such as manufacturability and full scale production. This will imply updates and modifications to existing designs.

To be able to verify whether the detailed designs produced during this phase will indeed comply with the requirements for the full SKA Observatory, a limited number of Elements may have to be built and thoroughly tested (see paragraph 5.3.2.1 for more detail). Any changes will be fed back and documentation updated prior to the review at the end of this phase.

During this phase the qualification testing¹ of assemblies and subassemblies will be completed. Qualification is the process whereby a design is proven.

The review to be performed at the conclusion of this phase is the System Critical Design Review (CDR). The Manufacturing Baseline is reached upon conclusion of the CDR.

5.3.1.4 Production

During the two production phases, products are manufactured, in accordance with the detailed designs produced during the previous phase, at various facilities. The two steps in production are

¹ Qualification Test Procedures will be kept distinct from Acceptance Test Procedures.

intended to qualify the manufacturing process before commitment to the larger scale required to complete the system. These products will be tested at the respective hierarchical levels and acceptance will conditional on the performance against the test procedures developed and agreed to during the detailed design phase.

Industrial standards and processes will be followed including emphasis on quality control, change management and configuration management of the equipment under fabrication.

Included in the production phase will be assembly, integration, testing and verification activities.

5.3.1.4.1 Assembly, Integration and Testing

During this phase, products will be integrated within the factory environment. Integration testing will be performed as the assembly and integration progresses to confirm conformity to interface control documents and requirements specifications. Tools and facilities to be used include emulators, simulators and mechanical test jigs and templates. It is important to identify and to begin any necessary development of these tools and facilities as soon as possible.

With the integration and testing completed, the product is ready for verification and acceptance testing within the factory environment. The phase will be concluded by the Test Readiness Review (TRR) to confirm that the product is ready for formal verification testing.

5.3.1.4.2 Verification

During this phase, the product will be formally tested against an approved Acceptance Test Procedure within the factory environment. The aim of the testing will be to confirm the compliance of the relevant product against its design and requirement specification and external interfaces prior to delivering the first products to the site (or integration facility).

This phase will be concluded with the performance of the formal Factory Acceptance Test (FAT). During this acceptance, all supporting test evidence, including qualification¹ tests, logistics tests and other tests already performed, will be presented to prove compliance of the product to the majority of the requirements. In exceptional cases a few tests will be allowed to be performed on site (or in the integration facilities) to prove compliance to requirements not testable in the factory. Acceptance testing is the process whereby both the design and the manufacturing are proven.

5.3.1.5 Site Integration and Testing

5.3.1.5.1 Site assembly, Integration and Testing

Once on site the products will be assembled and installed (probably to Element level) and set to work in a standalone fashion (for example each individual receptor of the dish array). A set of installation and integration tests will be performed during this phase and will conclude with a formal Site Acceptance Test (SAT) of the relevant Element.

This phase is more complex than it might seem because in some cases Elements might need the support of other Elements or products to be able to complete the SAT. Simple examples are power and cooling. Careful planning of the onsite roll out will therefore be needed. The source work for this detailed planning are the various Verification Plans drafted at an early stage.

5.3.1.5.2 System Integration, Verification and Acceptance

As Elements become available following their respective site acceptance tests, these Elements will be integrated into the system.

¹ If the qualification results obtained during the Detailed Design phase are still valid no re-qualification will be necessary and they can be confirmed at this point.

Depending on the eventual design and configuration of the Phase 1 telescope it is foreseen that the Sub-elements will be integrated to form an element before being integrated to form the user system. It may therefore be necessary to test and accept elements before the full integration, testing and acceptance of the user system is possible.

The phase will be concluded by the Acceptance Review. The Qualification Base Line is reached upon conclusion of the AR.

5.3.1.5.3 Commissioning

This phase will be aimed at establishing and proving the performance of the system against its original intent.

Commissioning is the process of setting up the system so that it can be verified against requirements. Activity geared towards addressing expectations not documented in requirements are not within scope.

5.3.2 Notes

The following principles are assumed to form a common culture across the SKA community.

5.3.2.1 *Testing, Verification and Acceptance*

From the description of the systems engineering phases above it should be clear that testing will be performed at all levels of the project starting at the lower levels. The aim is to test, qualify and accept equipment at their respective levels before delivery for integration into the level above. In this manner the testing and acceptance will flow up towards the eventual testing, acceptance and commissioning of the user system, and risk will be minimised.

Testing should be addressed from very early on. The requirement specification does include a section showing the verification and the kind and type of tests to be performed to prove compliance with each of the requirements.

The first Sub-elements, also called the first articles, to be delivered to Phase 1 will be thoroughly tested, their documentation audited and acceptance tests performed both in the factory and on site. As the production process continues, the testing and acceptance will be streamlined. The focus will shift to reduced numbers of tests to be performed and acceptance will increasingly be by similarity. This will be documented in the respective Verification Plans.

Testing will be done and results fed back to the manufacturing process before large scale production of Sub-elements will commence.

All acceptances will be performed against acceptance test procedures. These documents must contain detailed descriptions of the tests to be performed to achieve successful acceptance. Details will include test set-ups, test steps and expected results. Ideally the document will be used to record the test results and thereby form the Acceptance Test Results (ATRs) result document as well.

Tests within the acceptance test documents will be linked to the relevant requirement specifications in order to ensure traceability between the requirements established at the beginning and the test performed to prove compliance to the relevant requirements. In general it will be impossible to test all requirements of a system or element during a single event. For this reason the acceptance of Sub-elements has been divided among the various phases and includes both factory and site acceptance testing.

Testing will not be limited to functionality testing only and extensive qualification testing will have to be done during the initial stages of Phase 1. These tests will include both induced and natural environmental testing of assemblies and subassemblies. In addition an extensive RFI testing

programme will be conducted at various levels of the project to ensure compliance of equipment, both stand alone and integrated, to project RFI standards and requirements. Logistical aspects will also be tested and analysed. The requirements for all these aspects will be captured as part of the relevant requirement specification.

Integration plan(s) will be developed to guide integration and testing activities at all levels. These plans will have to be developed and finalised to the maximum extent possible during the Detailed Design phase.

5.3.2.2 *Software*

The development of software during the project needs careful consideration. In this regard, the SKA Office will work with the SDP and CSP consortia in the development of a Software Development/Engineering Plan addressing the aspects and elements of software development during each of the phases. Aspects to include in the plan are the development strategy across the phases, the documentation to be developed, the testing regime, quality, control and the roll out.

5.3.2.3 *Logistics and Support*

The logistical requirements for the SKA will be integrated into the project following the requirements analysis and validation phase of the user system. Apart from the development and delivery of the prime mission elements and Sub-elements, a significant set of tools, test equipment, special to type test equipment, spares, consumables, handbooks, manuals and other support equipment will have to be developed, integrated, tested and accepted. In this regard a Logistics Engineering Management Plan (LEMP) will be further developed (see paragraph 6.10 for more detail)

5.3.2.4 *Operations*

A key element and a major influence on the requirements at user system level is the Concept of Operations for the observatory. Work on this plan will continue throughout the development to ensure that requirements are captured and the design influenced to the extent required.

5.3.2.5 *SKA2*

The results obtained and lessons learnt during Phase 1 will be fed back and will have to be taken into consideration at the start of Phase 2.

6 System engineering activities

The System Engineering activities for Stage 1 of the Pre-Construction Phase at System level is provided in Table 2.

6.1 Project Glossary

To be able to 'speak the same language', a project Glossary will be developed. To enhance communication and avoid confusion and assumptions, the Glossary will be applicable to all parts of the project.

6.2 Work Breakdown Structures

The work breakdown structure is product based.

6.3 Interface Management

Interface definition and management is presented in [AD2].

Table 2 System Engineering WBS for Stage 1 of the Pre-Construction Phase

3 SKA.TEL.SE-SRR SKA Telescope System Engineering to System Requirements Review		
4 SKA.TEL.SE-SRR.APP		System Engineering Approach
4 SKA.TEL.SE-SRR.S2P		Stage 2 preparation
4 SKA.TEL.SE-SRR.M&T		SE Management and Tools
4 SKA.TEL.SE-SRR.TPR		Technical/Peer Reviews
4 SKA.TEL.SE-SRR.EMT		Enterprise Management and Tools
4 SKA.TEL.SE-SRR.CDM		Configuration Management/Change Control
4 SKA.TEL.SE-SRR.RMT		Risk Management
4 SKA.TEL.SE-SRR.PA		Product Assurance
4 SKA.TEL.SE-SRR.TDG		Integrated Task Teams/Domain Groups
4 SKA.TEL.SE-SRR.SDRA		Site Documentation Review and Analysis
4 SKA.TEL.SE-SRR.REN		Requirements Engineering
4 SKA.TEL.SE-SRR.MOD		Modelling
4 SKA.TEL.SE-SRR.ARC		Architecture
4 SKA.TEL.SE-SRR.IFD		Interface Definition
4 SKA.TEL.SE-SRR.VPL		Verification Planning
4 SKA.TEL.SE-SRR.DES		Design Specification
4 SKA.TEL.SE-SRR.ERA		Engineering Resource Allocation
4 SKA.TEL.SE-SRR.OPS		Operations
4 SKA.TEL.SE-SRR.SUS		Sustaining Engineering
4 SKA.TEL.SE-SRR.SDE		Software Development Environment
4 SKA.TEL.SE-SRR.RMO		Road Mapping & Obsolescence analysis
4 SKA.TEL.SE-SRR.STA		Standardisation Activities

6.4 Data Management

The data generated during the project will be captured within the design database (as described in paragraph 4.5.1.1) and as such will be submitted and managed as part of the central repository.

When submitting data to the repository it must be ensured that the data is complete, well referenced and well documented. There will be instances when it will be necessary to refer back to data in the repository and failure to comply with these guidelines will lead to confusion and rework.

6.5 Reviews and Audits

6.5.1 Technical Reviews

Throughout the lifecycle of the project a series of reviews will be conducted, each aimed at the establishment and confirmation of the appropriate baseline of the particular aspect/equipment under review.

Reviews support and facilitate internal and external project communications, and provides insight into the activities, results and the progress of the engineering effort in the project. It is important that reviews be well planned, well executed and well followed through. In this regard the responsibility will lie with the Project Manager, with delegation where appropriate to the relevant SKA Office Element System Engineer or System Engineer who will oversee the processes and make sure it complies with the guidelines set out in this document.

The following reviews (shown for the system but equally applicable to the Elements) have been identified as part of Phase 1:

- Conceptual Design Review (CoDR - completed)

- System Requirements Review (SRR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Production Review (PR)
- Test Readiness Review (TRR)
- Acceptance Review (AR)

The phasing and timing of each of these reviews for each Element are presented in the relevant statements of work.

Reviews will be conducted by releasing all the relevant documentation as a minimum 15 working days before the review date.

A process for conducting a review is summarised below and for each Review will be detailed in a separate organisation note.

6.5.1.1 Basic principles

Project reviews are examinations of the technical status of a project and associated issues at a particular point in time. Their primary purpose is to provide a comprehensive assessment of the project status against targets and requirements. Through independent participation, they give additional support to the project concerned at crucial stages and give the responsible management confidence in the technical progress being achieved. Additionally, reviews can identify potential lessons learned.

Reviews are carried out throughout the project life cycle, at all levels from Observatory downwards as appropriate.

The review purpose, mandate and documentation vary for the specific phase, stage of activity or level in the hierarchy of the project.

The efficiency of any review process is dependent upon the planning and organization of the review work, including specific assignment of responsibilities and the plan to close out the action items raised during the review.

6.5.1.2 Review tasks

6.5.1.2.1 Initiation of the review

This task comprises the assignment of review members to the review bodies, the preparation and release of the review plan and procedure and the assessment of the prerequisites.

6.5.1.2.2 Preparation and distribution of the review data-package

This task comprises the preparation and distribution of the documentation as defined in the review procedure. In a kick-off meeting review participants are familiarized with the review objectives and the documentation submitted for the review.

6.5.1.2.3 Review of the documentation

This task comprises the detailed review of the review data-package including additional information provided in the kick-off presentation. Identified problems, questions and solutions arising from the examination of the documentation are recorded.

Collocation meetings between the review team and the SKA Project/Community serve to solve issues raised, to consolidate findings and to provide recommendations for item closure.

Finally a report is issued on the behalf of the review team, synthesizing the results of the review and identifying major issues for attention of the SKA Office.

6.5.1.2.4 Review findings and conclusions

This task comprises the examination of the review team findings, confirmation of the recommendations, decisions for follow-up activities and confirmation of the achievement of the review objectives.

6.5.1.3 Review Descriptions

High level descriptions of the reviews are presented in subsequent paragraphs. The detail within each of these paragraphs will be refined and expanded following review and agreement on the philosophy behind each of the reviews.

6.5.1.4 Concept Design Review (CoDR) - completed

A Concept Design Review (CoDR) will be conducted at the end of the concept phase.

The aim of the CoDR is to confirm that the 'problem' has been thoroughly explored and is well understood. This is important to be able to move forward to the next phases of the project where technology options will be investigated and selections being made. The review will also focus on whether the first order solutions that have been identified are indeed appropriate and will ensure that agreement is reached on the option(s) to be carried forward.

Documents to be reviewed during the CoDR will include at least:

- Report outlining the findings of the investigations of the first phase including descriptions of competing technologies and statements and justifications of the candidate options to be carried forward
- First draft requirement specification, with supporting data such as calculated or estimated performance parameters
- Context diagram identifying all relevant interfaces (internal and external)
- First risk register and related mitigation strategies
- First draft block diagram of the relevant system, element or Sub-element
- First draft requirements traceability matrix/database
- Strategy and plans for proceeding to the next phase
- First draft cost, schedule, power and RAM estimates
- Logistic planning
- Identification of software and related software documentation activities that will be conducted

6.5.1.5 (System) Requirements Review (SRR)

The SRR, conducted at the end of the definition phase, will review primarily the definition of the specific building item¹ as reflected in its relevant Requirement Specification. The review will typically be conducted after the conclusion of the requirement analysis and validation activities.

Documents to be reviewed during the SRR will include:

¹ The term 'item' is used generically to represent any of the building blocks in the system hierarchy.

- Finalised requirement specification (including the cross verification matrix indicating the kind of tests to be performed for each of the requirements).
- First draft of the architectural design description document
- Updated block diagram of the relevant system, element or Sub-element
- First draft interface control documents (internal and external)
- First draft verification plan/procedure
- Updated risk register and related mitigation strategies
- Updated requirements traceability matrix/database
- Report outlining the findings of the investigations of the candidate technology options and statements and justifications of the selected baseline option to be carried forward
- Strategy and plans for proceeding to the next phase
- Updated Cost, schedule, engineering resource and RAM estimates
- Logistical and software documents (To be defined)
- First draft health and safety plan

The output of this review is a well-defined item at the project level at which it is being performed.

6.5.1.6 Preliminary Design Review (PDR)

The PDR will be conducted at the end of the preliminary design phase and is aimed to review and confirm the final design of the item as reflected in its relevant Architectural Design Description Document. The review will be performed at the conclusion of the functional analysis, verification, synthesis and design verification activities at the end of the preliminary design phase.

Documents to be reviewed during the PDR will include:

- Revised and final requirements specification
- Final architectural design description document
- Final interface control documents (internal and external)
- Final block diagram
- Acceptance test plans and procedures
- First draft integration plan
- Updated requirements traceability matrix/database
- First high level estimate of consumables, spares and test equipment
- Updated risk register and relating mitigations strategies
- Updated Cost, schedule, engineering resource and RAM estimates
- Upgrade plans
- Roll out/build plans
- Logistic Engineering Standards & Procedures
- Audit of manufacturing datapacks for designs to be carried forward
- Safety analysis
- Final health and safety plan

Together, the above set of documents must reflect the fully costed design of the item. The output of the review will be a fully designed item at the project level at which it is being performed at.

6.5.1.7 Critical Design Review (CDR)

The CDR will be performed at the end of the detailed design phase and will determine whether the item under review is ready to enter the preliminary production phase. The following high level activities are foreseen:

- Confirmation of the requirement specification and design description baseline
- Review of all aspects of the production process as well as the supporting documents (manufacturing datapacks).
- Review of test and verification plans/procedures
- Review of updated risk registers
- Presentation of final design data on costs, engineering resource utilisation, reliability etc.
- Review of integration and test plans

The exact details of this phase will be developed and expanded during the early Pre-Construction Phase.

6.5.1.8 Production Review (PR)

The production review will be performed at the end of the preliminary production phase. The main aim of this review will be to confirm that the items produced do comply to specifications and is ready to go into full scale production. In this regard test and verification results will be reviewed and manufacturing datapacks will be audited. The output from this review will be utilised in the full scale production phase to produce the items against the approved set of baseline documents.

6.5.1.9 Test Readiness Review (TRR)

The TRR is performed in order to establish whether the specific item is ready for formal testing. This will imply that integration and integration testing are complete and evidence and proof of test results can be presented.

The aim of the review will be to verify the readiness of the equipment itself, associated test documentation, and test facilities and equipment in order to start with formal testing/verification.

As a minimum the following will be reviewed during the TRR:

- a) Overview of input documents and process followed to establish baseline
- b) Results of the development testing performed on the equipment
- c) Acceptance Test Procedure (including qualification requirements)
- d) Requirement traceability matrix/database
- e) Confirmation of the configuration of the equipment to be tested
- f) Readiness of equipment
- g) Readiness of test equipment and simulators
- h) Readiness of test facilities
- i) Requirements traceability matrix/database
- j) Identified risks and mitigation plans

6.5.1.10 Acceptance Review (AR)

The AR will be performed following the conclusion of the verification of the equipment. The aim of the review will be to confirm the completeness and the results of the verification phase. The review will take the form of a Functional Configuration Audit (FCA) and a Physical Configuration Audit (PCA).

The FCA is a formal audit intended to confirm that the equipment has achieved the performance and functional requirements; that it satisfies the characteristics specified in the relevant specifications, interface specifications, and other baseline documentation; and that test plans and procedures were complied with.

The PCA is intended to confirm the physical configuration of the equipment that was tested and to establish the “as-built” configuration.

As a minimum the following will be reviewed during the AR:

- a) Overview of input documents and processes followed to establish the baseline
- b) Factory/site acceptance test reports (including qualification test results)
- c) Change proposal register
- d) Deviations/waivers
- e) Requirement traceability matrix/database
- f) Manufacturing datapack
- g) FCA and PCA reports

6.6 Requirements Traceability

Requirements traceability will ensure that all requirements from the science and elsewhere find their way down to the lower levels via the user system level and it will be performed throughout the system engineering process. All requirements will be linked to higher level requirements and traceable from requirement specifications, through design documents, through interface control documents (including operator interface documents) down to acceptance test procedures. It is important to establish the link between requirements, supporting design data and, information within the design database because by providing the original context in which a requirement was selected, any future reconsideration of the requirement can determine if the original constraints are still valid [RD7].

Requirements traceability will be presented and reviewed at each of the technical reviews described in the previous paragraphs up to, and including, the final acceptance of the user system.

Ideally each requirement from the highest to the lowest level of the project have to link to a parent requirement. Requirements without parents will either represent a locally introduced ‘nice-to-have’ or a missing requirement at the higher level. If it is the former, the existence of the requirement must be carefully considered, and if justification can be found, it may be incorporated into the baseline. In the event of the latter, the requirement must be rolled back up to ensure completeness of the requirements at the higher level.

6.7 Baseline establishment

The definition of a new baseline is a process that includes the SKA project scientists, the SKA architect and the SKA consortia inputs into the design process.

6.8 Configuration Management

Because of the distributed nature of the project it will be important to keep control of the configuration of all items, data and information generated during the project. Apart from the obvious management of documents (in a Document Management System) , the configuration

management tools will also include the management, control and release processes for hardware, firmware, FPGA/ASIC designs (gateway) and software.

Configuration management includes:

- Document numbering and version control to include one page information documents such as block diagrams, timelines and other drawings.
- Management of part numbering and hierarchical structures from the highest to the lowest level.
- Management of software, firmware and gateway version number and releases.
- Management of PC board designs and documentation with related numbering and control of the boards themselves.
- Establishment and management of history and route cards for (especially) hardware reflecting the steps within the build process of the equipment and the status of each of the steps.

A comprehensive configuration management system and configuration management plan will, be established and developed.

6.9 Change Management

The Change Management process is presented in [AD3].

6.10 Logistics

The logistics and support requirements of the project will form an integral and important part of the design and in the words of the logistics engineers:

Design for support, design the support, support the design!

To guide and direct the logistics activities on the project a Logistics Engineering Management Plan (LEMP) has been developed [RD9]. Within this plan the following concepts have been addressed:

- a) Maintenance
- b) Personnel
- c) Training
- d) Support publications (manuals and handbooks)
- e) Supply support (spares and consumables)
- f) Packaging, handling, storage and transportation
- g) Support and test equipment
- h) Support facilities
- i) Support data handling
- j) Guidance on reliability, availability and maintainability analysis and activities

All aspects will be applicable to the eventual Phase 1 instrument and will need to be addressed early.

6.11 Quality

A Quality Assurance Plan can be found in [AD4].

7 Transitioning High Risk Technologies

The SKA programme will involve the development of immature technologies, some of which have been already identified and catered for in the Advanced Instrumentation Programme.

In support of the fully costed user system design, it will be necessary to make technology choices at the appropriate stage to develop the selected technologies to a maturity level commensurate with the aims and deliverables of the development.

For high risk technologies not forming part of this baseline design two options exist. The first option is to terminate the developments at that stage while the second option will entail further development of the option but on a parallel path to the baseline design effort.

At a specific point in time (exact point still to be established) the technology will be assessed yet again and this time three options exist – terminate, introduce into the project or continue with parallel development. It must be emphasised that the longer the parallel development path is pursued, the more difficult it will be to introduce the technology into the facility being built.

The level of maturity of the technology will be reflected in the extent to which the risk has been retired (including cost, schedule and performance aspects) and their analysis will play a significant role during the technology decisions milestones.

The majority of technologies being considered for the SKA at this point in time are high risk and therefore require the risk management programme to be initiated as soon as possible. The first order of business will be to identify the highest risk areas to be addressed as part of the verification programmes and to develop the strategies within these programmes to address these risks.

Table 3 Technology Readiness Levels Definitions

Readiness Level	Definition	Explanation
TRL 1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development.
TRL 2	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented and R&D started. Applications are speculative and may be unproven.
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept	Active research and development is initiated, including analytical / laboratory studies to validate predictions regarding the technology.
TRL 4	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together.
TRL 5	Component and/or breadboard validation in relevant environment	The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment.
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (housed or exposed)	A representative model or prototype system is tested in a relevant environment.
TRL 7	System prototype	A prototype system that is near, or at, the planned

	demonstration in a real operational system. environment	
TRL 8	Actual system completed and qualified through test and demonstration (housed or exposed)	In an actual system, the technology has been proven to work in its final form and under expected conditions.
TRL 9	Actual system proven through successful observatory operations	The system incorporating the new technology in its final form has been used under actual mission conditions.

8 Additional System Engineering Activities

8.1 Tools

Tools for the implementation and control of the systems engineering process are still under investigation. The Systems Engineering group will play a significant role in the choice of tools to be utilised because it will have to be project wide.

8.2 Safety

Safety is always a primary concern and will have to be folded into the project. A safety plan will have to be developed addressing all the aspects of safety on the project and especially during Phase 1. An analysis of the safety of the design and its operation must be maintained and reviewed as the development proceeds.

8.3 Standardisation

Because of the enormous quantities of components that will have to be procured during the SKA development and roll out, significant value will be obtained by initiating and implementing a standardisation programme. Guidelines in this regard will be developed by the SKA Office system engineer and will eventually be the responsibility of the SKA Office Element System Engineers and other systems engineers to implement within their domains.

8.4 Obsolescence

Because technology choices will have to be made quite 'early', the risk of obsolescence will be significant and will have to be managed. Technologies assessed at the technology decision milestones will be evaluated for obsolescence risks that are being faced. The SKA Office Element System Engineers will ensure that data are gathered to enable the assessment of the risk during these events.

8.5 Human Engineering

Human engineering will form an integrated part of the systems engineering process. During the development attention will have to be paid to the human engineering aspects. The scope and depth of this work still have to be established.

Human engineering includes:

- Task analysis
- Role descriptions
- Job descriptions

- Safety
- Ergonomics
- Training

8.6 Redundancy

A high level analysis of the reliability and availability aspects of the system will be done during the Definition phase of the project. The intention of this analysis is to confirm possible redundancy requirements for the system to be included in the system design and costing activities. During this analysis safety aspects will also have to be taken into account.