SYSTEM ENGINEERING MANAGEMENT PLAN

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LIST OF ABREVIATIONS

AAVP .... Aperture Array Verification Program
APERTIF........... APERture Tile In Focus
AR .... Acceptance Review
ASKAP .... Australian Square Kilometre Array Pathfinder
ATP................. Acceptance Test Procedure
ATR................. Acceptance Test Result
BIT.................. Build In Test
CCB................. Configuration Change Board
CDR .... Critical Design Review
COAR.............. Consolidated Observation Action Register
CoDR .... Concept Design Review
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
LWA................ Long Wavelength Array
MeerKAT .... The precursor array being build 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
PCA................. Physical Configuration Audit
PDR................. Preliminary Design Review
PPR .... Pre-production Review
PrepSKA.......... Preparatory phase for the SKA
RAM................ Reliability, Availability and Maintainability
Rev .... Revision
RFI .... Radio Frequency Interference
RSP .... Reference Science Plan
SAT .... Site Acceptance Test
SEMP .... System Engineering Management Plan
SKA .... Square Kilometre Array
SKADS .... SKA Design Studies
SPDO .... SKA Program Development Office
SRR .... (Sub)System Requirements Review
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
WP2................ PrepSKA Work package 2
WP3................ PrepSKA Work Package 3

1 Introduction

1.1 Purpose of the document

The Square Kilometre Array (SKA) project has been ongoing for several years and has now reached a stage where many engineering activities will be conducted in parallel at various 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 in the project 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 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 telescope, including maintenance and support capabilities, on the selected site.

This SEMP 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.

[1] None

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:

[2] R.T. Schilizzi et al., '*Memo 100 – Preliminary Specifications for the Square Kilometre Array*', dated December 2007.

[3] P.E. Dewdney, *'Guiding Principles, Activities and Targets for PrepSKA Work Package 2'*, Version 2.4, dated 2 November 2008.

[4] R.T. Schilizzi, P.E. Dewdney and C. Greenwood, '*Project Management Plan for the Square Kilometre Array, 2008-2012*', Reference SSEC 080723-9.3a, Draft v1.6, dated 17 July 2008.

[5] P.E. Dewdney, '*SKA Science-Technology Trade-Off Process*', WP2-005.010.030-MP-004, Rev 1.1, dated 2010-01-20.

[6] K. Cloete, '*Risk Management Plan*', document MGT-040.040.000-MP-001, Rev 1, dated 2009-08-03.

[7] ISO/IEC 26702 (IEEE Std 1220-2005), *'Systems engineering – Application and management of the systems engineering process'*, dated 9 September 2005.

[8] INCOSE Publications, *'Systems Engineering Handbook – A guide for system life cycle processes and activities'*, V3.1 dated August 2007.

[9] 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.

[10] K. Cloete, '*PREPSKA Documentation Standards, Handling and Control*', document number MGT-040.010.010-MP-001, Rev C, dated 2009-04-02.

[11] D. Liebenberg, '*SKA Logistic Engineering Management Plan (LEMP)*', document number WP2-005.010.030-MP-002, Rev C, dated 2010-01-18.

[12] P. Dewdney et al., "*SKA-Phase 1*: *Preliminary System Description*", v2.1, SKA Memo 130, Nov. 2010.

[13] M.A. Garrett, J.M. Cordes, D. De Boer, J.L. Jonas, S. Rawlings, and R. T. Schilizzi (SSEC SKA1 Sub-committee), "*Concept Design for SKA1 (SKA$_1$)*", SKA Memo 125, Aug. 2010.

3 Introduction

An overall high level schedule for the Square Kilometre Array (SKA) project is shown in Figure 1 and it can be seen that the project is currently within the Preparatory SKA (PrepSKA) phase. During the preceding years many working groups and task forces have been active across the globe defining and refining the SKA science and engineering. This has resulted in the publication of many documents and memos forming a solid base from which PrepSKA could be launched.

One of these memos, Memo 100 [2], captured and presented the baseline design of the instrument. During the review of this document by the SKA Specification Review Committee it was suggested that a reference science mission be developed against which this design could be measured. This lead to the development of the Design Reference Mission (DRM) (formerly known as the Reference Science Plan (RSP)) which has official release status. From the platform and baseline established by these two documents (Memo 100 and DRM) the work for the next few years will move forward to the eventual goal of delivering a fully costed system design by the end of PrepSKA.

Against the background of the proposed 'full' SKA, a subset has been proposed as a Phase 1. This SEMP equally applies to this first stage programme and has not been tailored.

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

The current high level SKA block diagram is shown in Figure 2[1]. As presented in this figure the SKA will not only consist of very many elements and subsystems, it will be physically spread out across thousands of kilometres on the selected site and even across the globe. This aspect together with the fact that the design work is spread around the globe as well, makes the adoption of a coherent system engineering view on the project critical to its success. It is in this context that this Systems Engineering Management Plan (SEMP) has been developed.

[1] Note that Figure 2 does not represent any design decisions. Trade-offs still have to be performed and location and outlay of the system elements might change.

3.1 What is System Engineering and Why is it Important to the SKA

For a project as large and complex as the SKA, the adoption and execution of a systems engineering approach is a requirement and not an option. Examples are spread throughout industry, military and large science projects where the systems engineering approach has been adopted and is being used with great success, but the question might remain – what is systems engineering?

Numerous definitions of System Engineering are in existence. Examples are:

a) 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)

b) 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.

The ability to influence the final life cycle costs of any system is particularly significant during the early stages of the project. As the project progresses **the decisions or even worse, the non-decisions,** which were made or not made upstream, will impact the project downstream. It has been shown that the costs associated with implementing changes late in a project can be orders of magnitude greater than the cost that would had been incurred have the change been implemented early on in the process. Changes are of course not only limited to mistakes that have been made, but also include the late addition of requirements to the system due to aspects that were forgotten or neglected at the start of the project or even the removal of requirements and features. It is within this context that the strength and importance of the systems engineering approach can be found.

With all of this in mind and taking into account that the SKA is a highly complex, large and very distributed (in terms of institutions and work being performed) project, 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 all the way through to the disposal phase of the project.

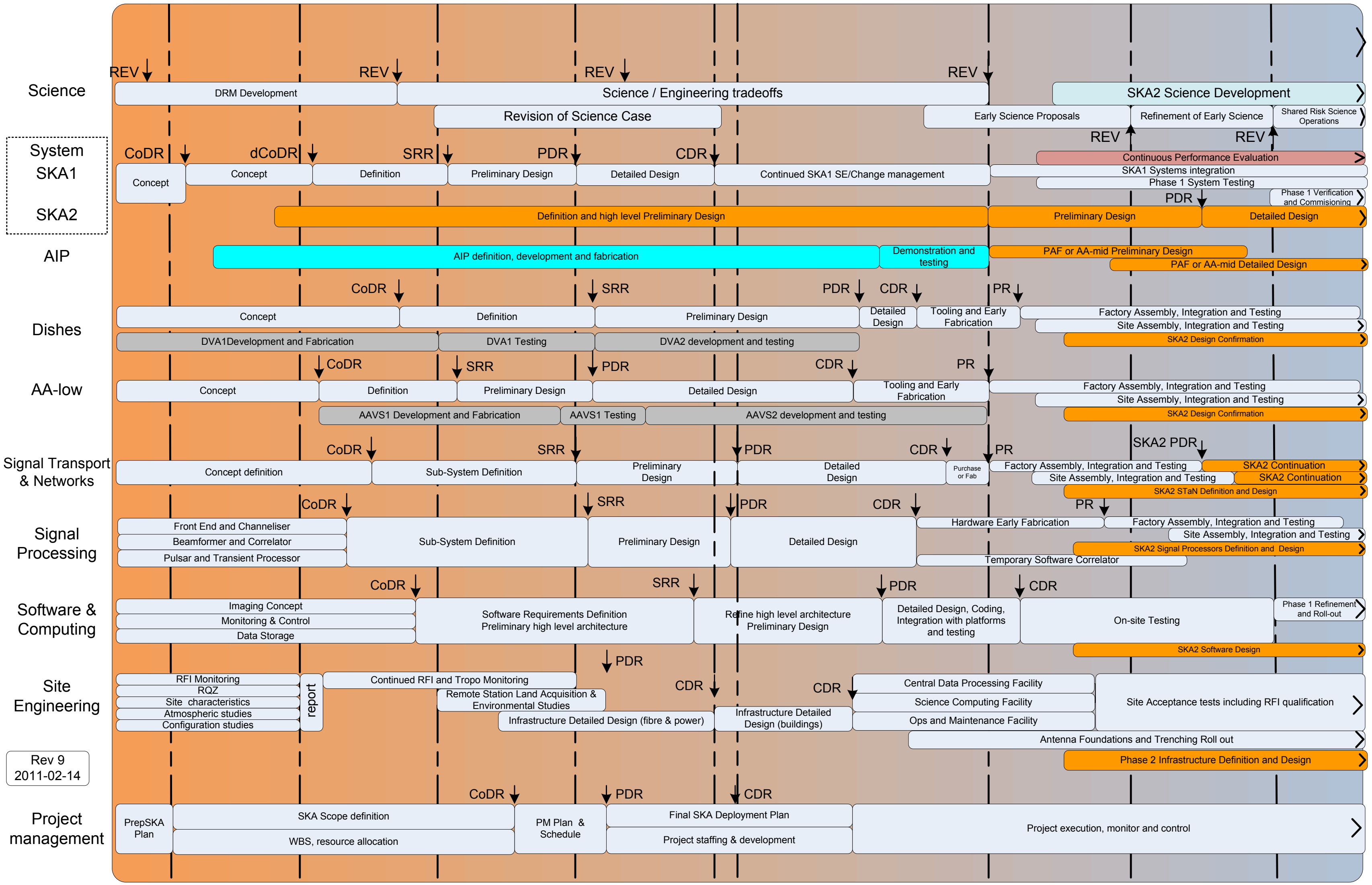

Figure 1: SKA Overall Flow.

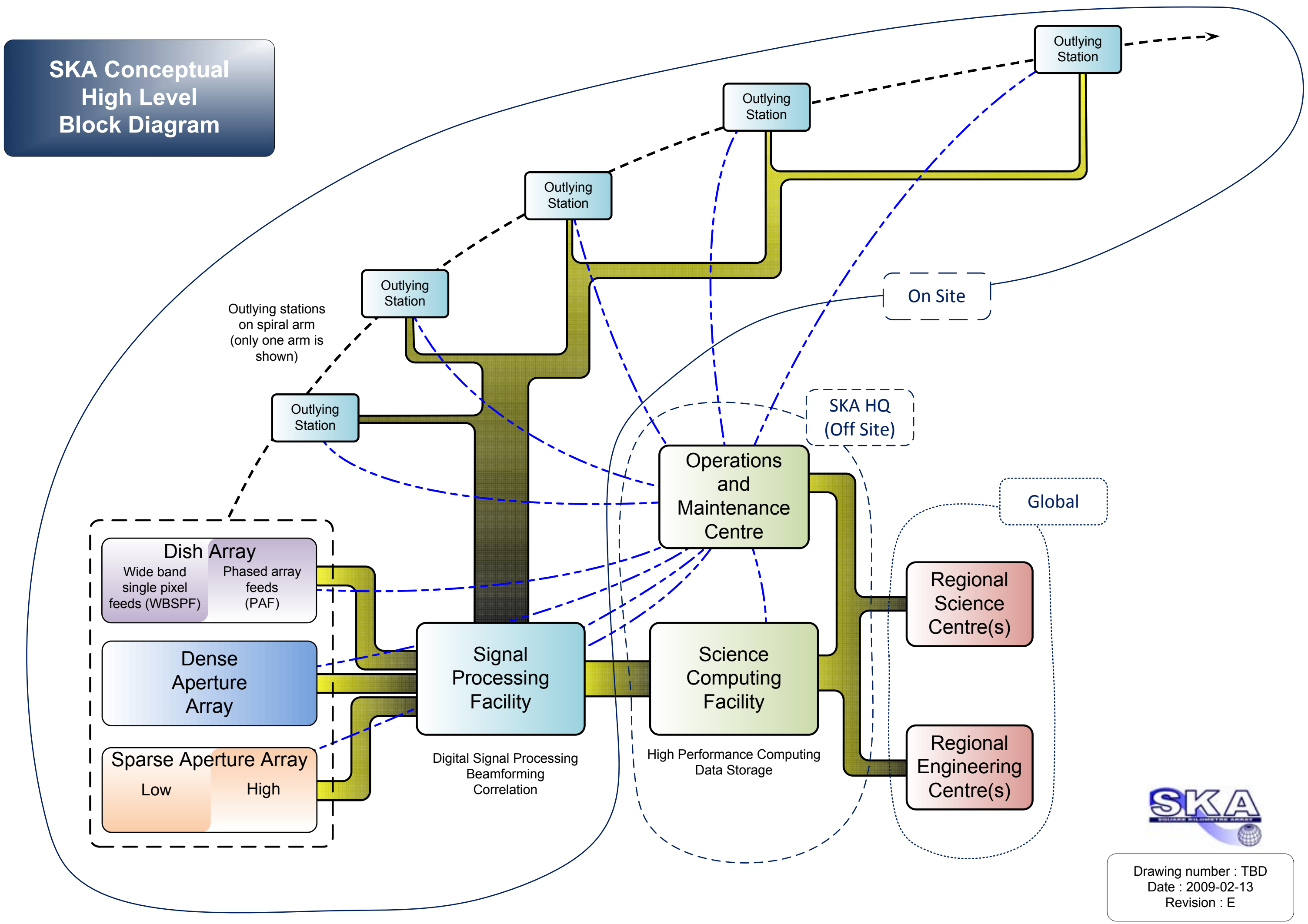

Figure 2: SKA High Level Block Diagram.

3.2 Project Phases and Transitions

The SKA project has been subdivided into various phases as shown in Figure 1. Although the transitions between the phases are shown as single points or events in time, these transitions will, in practice, 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 primary construction phases of the project are Phase 1 and Phase 2. These are separate phases imposed mainly due to funding reasons. They also serve to reduce risk: Phase 1 will serve as a final confirmation of the production baseline before the 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 roll-out of equipment on site will escalate with resulting increase in installation, acceptance, integration, commissioning and support requirements. Throughout the PrepSKA design activities this escalation requirement will be taken into account and will form part of the final PrepSKA deliverables. The PrepSKA deliverables will include plans, activities and costs for scaling 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 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 PrepSKA 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.

In the event that there is significant introduction of improved technology between Phases 1 and 2 (necessitating the obsolescence of major parts of the system) the details of the Plan will be changed to reflect the necessary increase in qualification and verification activity.

Also shown on Figure 1 is the proposed system engineering phases at the user system level and at element level and their relative alignment with the project phases and other milestones. The details of the system engineering phases are described later in this document.

3.3 General System Engineering Philosophy

Because the SKA, as defined in [2], is a combination of very complex technologies of which many are not mature, the risks that the project will be facing are high. A rigorous single pass top down system engineering philosophy in this kind of environment will therefore not deliver the optimum solution and eventual successful implementation and roll out of the SKA system. The model that will be adopted will lean more towards the spiral approach whereby requirements and potential solutions and designs are iterated and refined. This approach supports the philosophy as put forward in [3]. However, it must be emphasised that although a spiral model is adopted, the steps within the system engineering process (as described in paragraph 5) must still be executed faithfully and comprehensively.

A graphical representation of the iterative process is given in Figure 3. From the Observatory level the iterations and trade-offs will be strongly linked to the science requirements. 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 requirements are currently being developed through a series of case studies and are captured in the Design Reference Mission. These case studies have been selected to form the upper "envelope" of science requirements. A method for objectively carrying out the necessary science-technology trades has also been developed (see [5]). The method is based on the performance, cost and risk of the relevant technologies and the science return of the relevant science areas. The process of making the trades will be carried over time and expressed as a gradual narrowing of options as the system design reviews progress. Performance, cost, risk and science return will underlie the deliberations at each review stage.

Because of the iterative nature the work to be done will include refinement of technologies and requirements at the subsystem level, which will provide feedback and inputs to the element and system levels of the project. A good example of this process is the dish verification program. These inputs from the lower levels will also be utilised in the trade off studies and eventual refinement of the system level requirements and design. Refined requirements will be re-allocated back to the lower levels and the iteration will be repeated. At different levels the iterative process may be repeated more than once.

The primary output of the process by the end of PrepSKA will be a fully defined and costed system design supported by defined and costed elements and subsystems.

The fact that the system engineering process is concurrent at a number of levels will provide numerous challenges and 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.

The process will start at the defined baseline of Memo 100 [2] and the DRM. Other groundwork performed thus far will also be utilised but care must be taken to ensure that the gaps that currently exist in this work are identified and are addressed.

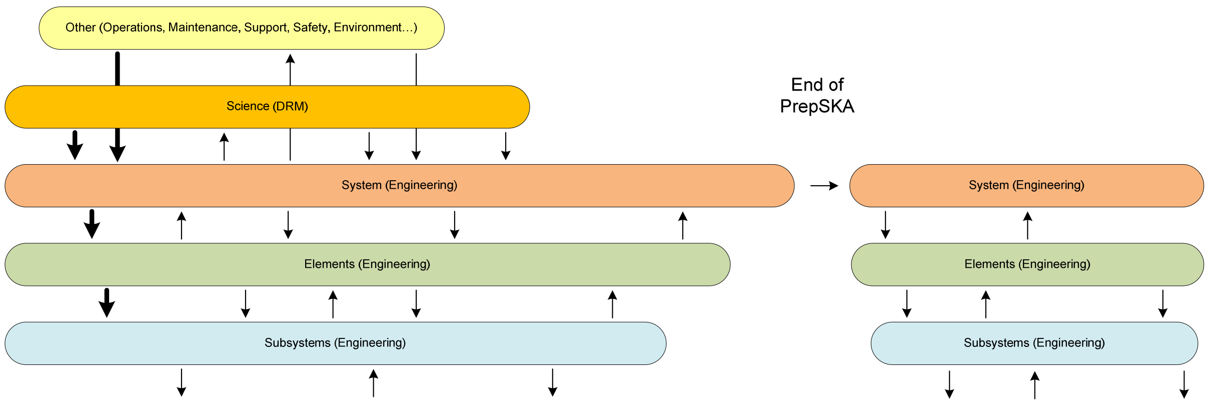

Figure 3: SKA Project Iterative Process**.**

4 System Engineering Process Planning

4.1 Organisational Responsibilities and Relationships

The organisational responsibilities have, to a large extent, been set out in detail in documents [3] and [4]. In summary the SKA Program Development Office (SPDO) has domain specialists in various fields that will, under direction of the SKA Project Engineer, plan and lead the activities within each domain. Each of these domain specialists will be responsible for the implementation and execution of the system engineering activities for hardware and software within his/her domain. They will ensure that the system engineering approach flows down into the relevant lead and supporting institutions to an acceptable level and detail to support the overall system engineering effort.

All verification programs will adhere to the methodology and philosophy as described in this document. It is expected that each of the verification programs will be led by a system engineer and/or a project engineer or the relevant SPDO domain specialist. In cases where the activities are not led by the SPDO domain specialists the relevant system/project engineer will be clearly identified and will form part of the System Engineering Group to ensure integration and coherence of the verification program with the overall SKA system engineering effort.

4.2 Integration of the global System Engineering Effort

The global effort outside the SPDO has been divided into the following three categories (as approved by the SSEC):

- Precursor: A telescope on one of the two candidate sites which includes ASKAP, MeerKAT and MWA.
- Design Study: A study of one or more major sub-systems of the SKA design, including the construction of prototypes and includes the Canadian SKA Program, TDP, SKADS and AAVP.
- Pathfinder: SKA-related technology, science and operations activity and includes LOFAR, EMBRACE, APERTIF, LWA, ATA and EVLA.

To establish and ensure a coherent system engineering approach and coordinated efforts within and across the levels of the SKA project, a System Engineering Group, lead by the SPDO Systems Engineer, will be established. Attempts will be made to include as much as possible of the global activities and groups, as set out above, in the System Engineering Group.

The proposed members of this group are:

- SPDO Project Engineer
- SPDO System Engineer
- SPDO Domain Specialists for Receptors, Signal Transport and Networks, Digital and Computing and Software (at least during the initial stages)
- SPDO Site Engineer (WP3)
- AAVP Project Engineer and AAVP System Engineer
- ASKAP and MeerKAT project/system engineers
- NRAO representative(s)
- Pathfinder representatives (to be confirmed)

Although WP3 is a separate PrepSKA work package, the work and outputs from this work package will influence the design of the SKA significantly and therefore need to be included and integrated into the SKA system engineering effort.

Although the precursor arrays are, to a large extent, aimed at the development of instruments in their own right, a significant amount of work that will be performed as part of the precursor array(s) development are relevant to the SKA. Inclusion of the precursor array system/project engineers within the System Engineering Group will aid continuous and effective communications between the SKA effort and the precursor arrays. It will be the responsibility of the precursor array system/project engineers to ensure that information and documentation relevant to the SKA effort produced specifically for, or as part of the precursor development, and especially site specific studies and designs, be made visible and available to the SPDO System Engineer for information and in support of the SKA design activities.

Interactions with the pathfinders will have to be strengthened. It is not proposed at this stage that all the pathfinder system/project engineers form part of the System Engineering Group but regular contact, interaction and especially information exchange will have to take place. Details of how this interaction will be established are TBD.

It must be emphasised that the main focus of the System Engineering Group will be the design aspects of the SKA at system and user system level. Although not all the members as listed above are directly involved in the SKA effort (for example the NRAO representatives), they are included because of their extensive experience with array development which will be very valuable as input to the SKA effort.

It is foreseen that the System Engineering Group will meet quite regularly during the initial period of the PrepSKA phase in order to create a solid system engineering foundation early on in the project. Meetings will be conducted primarily via tele-conferences but face to face interactions and meetings of this group will have to take place to focus on and discuss system and system engineering issues within the project. In addition it is strongly recommended that SPDO domain specialists be invited to participate in design reviews of the precursor, design study prototypes (such as the A3IV) and other pathfinder design reviews to enhance the communication of relevant design knowledge to the SKA project.

Each of the SPDO domain specialists will set up an SKA Engineering Design Group within their domain and lead and coordinate the activities and discussions within those groups. Although these meetings will focus heavily on technical issues within the domain, time will need to be allocated to discuss the system engineering issues within the domain on a regular basis.

4.3 System Hierarchy

In order to structure the system engineering effort a system hierarchy will be developed and the first draft proposal of this hierarchy is shown in Figure 4 (a and b).

The project will be divided into several levels (layers). Within each of the levels there are various building blocks and each of these are linked to higher and lower level building blocks. For example – the eventual SKA User System (level 7) consists of the telescope, people and facility systems at level 6. In turn the telescope will consist of the dish array, sparse aperture array (high and low), dense aperture array, signal processing, signal transport and networks, computing and software, power and site infrastructure elements at level 5.

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.

The hierarchy will also facilitate better communication and understanding and aligns terminology throughout. It provides a clear view of where requirements for each of the blocks originate and how the flow down of the process will be achieved.

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 dish array will be developed. This Requirement Specification will receive its inputs from the telescope system and will in turn allocate requirements to its major subsystems which in this example are the dishes, wide band single pixel feeds and phased array feeds.
- Requirements traceability will follow the links between the building blocks and levels. For example the requirements for the sparse aperture array will trace its requirements to the telescope which in turn will trace its requirements to the user system.
- The hierarchy also serves as a definition of responsibilities. Each building block has to be allocated to a person who will be responsible to ensure that the systems engineering work within that building block is being carried out in accordance with the top level SKA system engineering plan and procedures.

It will be possible to add or remove 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 used as an example 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.

Aspects that will need to be considered during the tailoring of the hierarchy include a view on where the bases will be covered when any of the blocks are taken away and what is the view on the eventual testing and acceptance. For example – if it is foreseen that the dish array will be tested and accepted separately from other elements, it will be necessary to firstly have a dish array element and to develop a requirement specification for this array against which eventual testing and acceptance will be performed.

It is proposed that the hierarchy be reviewed within the Systems Engineering Group at the same time as the review of this SEMP.

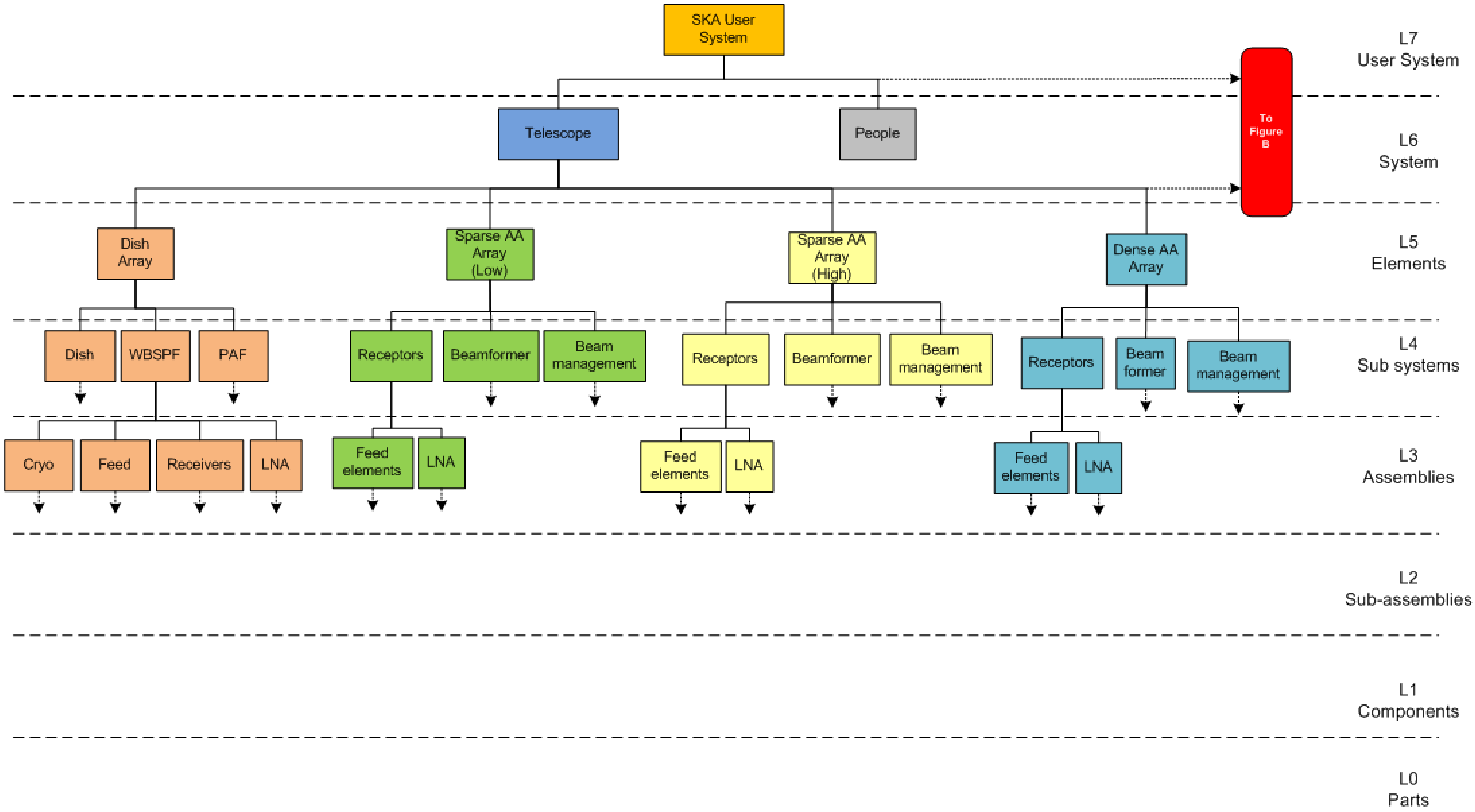

Figure 4a: SKA System Hierarchy**.**

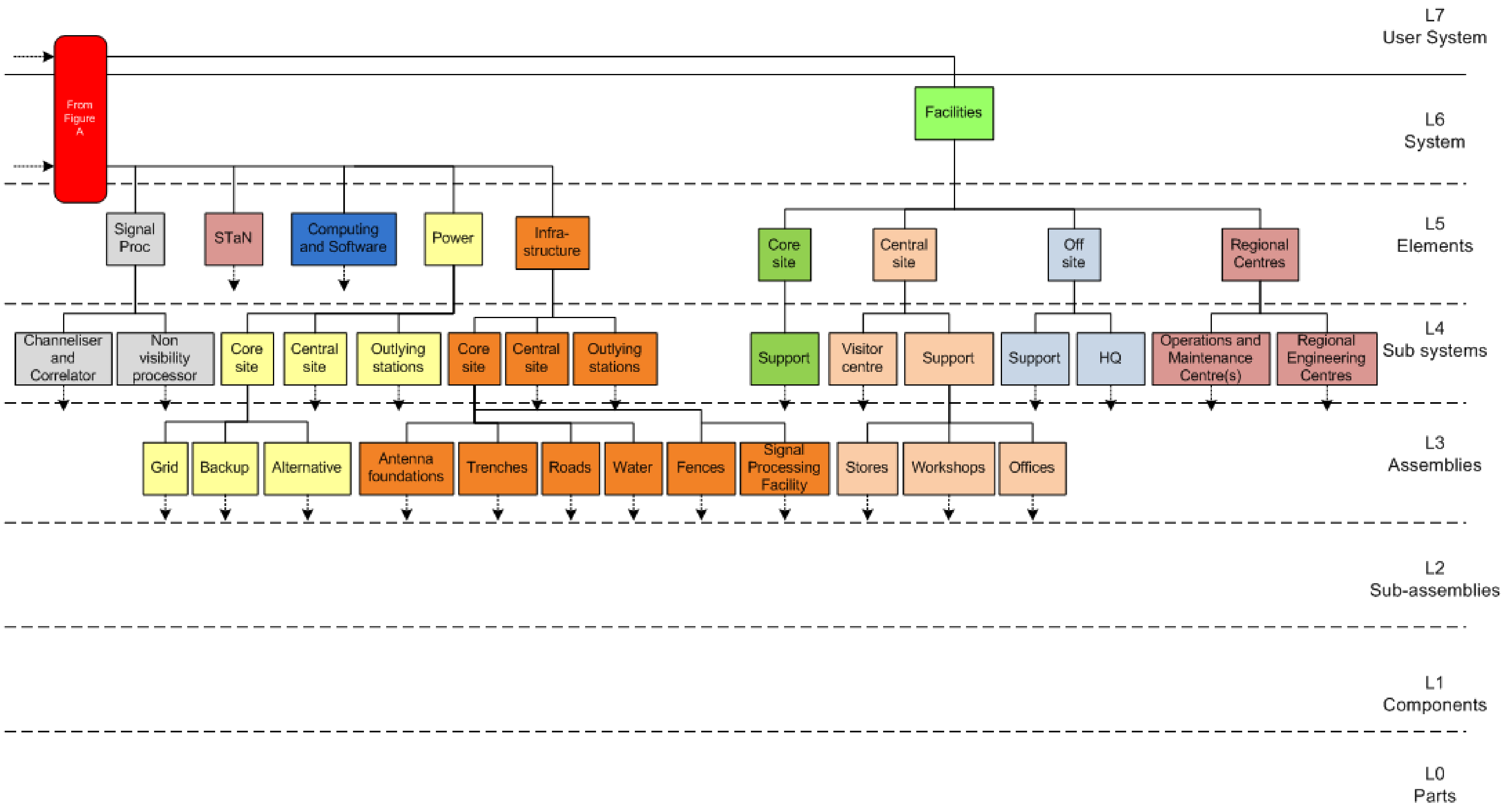

Figure 5b : SKA System Hierarchy

4.4 Major Deliverables

The eventual aim of the project is to deliver a cost effective, fully operational and fully supportable SKA user system. However, in achieving this aim the deliverables for the various phases will differ. Because of the uncertainty in the design of the full SKA the focus in this section will be on the deliverables for PrepSKA and some guidance will be provided for Phase 1.

4.4.1 PrepSKA

4.4.1.1 Documentation

Throughout the PrepSKA phase many studies, analyses, tradeoffs, specifications, interface control documents and other documents will be developed. Apart from this technical documentation an expected number of plans, standards, philosophies, reports and other management and technical artefacts will also be created. The end result will be a collection of many documents and as stated in [3], the legacy of PrepSKA will lie within this documentation.

The complete list of documentation to be developed during PrepSKA and beyond will not be listed here. Some high level guidance on the technical documentation can be found as part of the description of each of the technical reviews. Details still have to be expanded and documents and document types will be refined. In general it can be stated that the documentation will include:

- A completed and agreed to design reference mission (DRM)
- A completed and agreed to science operations plan (SOP)
- A completed and agreed to maintenance and support plan (M&SP)
- Requirements specifications for each of the systems
- Designs for the systems
- Requirement specifications for all elements of the system
- Designs for all elements of the system
- Architectures for software elements
- Requirements specifications for all subsystems of the elements
- Designs for all subsystems of the elements
- Interface control definitions and interface designs at all levels
- Results of the tests performed on the verification models
- Scaling analysis (where applicable)
- Deployment plan
- Upgrade Plan
- Fully costed user system breakdown

In a few cases the activities will be taken down to part level and therefore detailed design documentation (such as mechanical design drawings) will be generated and be delivered as part of PrepSKA. With respect to the management, documentation guidance is provided in the Project Management Plan [4]. This includes the Project Book, Project Dictionary and Document Control Plan.

Two aspects that need to be highlighted are the creation and upkeep of design files (part of the design documentation but not the complete design datapack) and the development of separate operator interface control documents.

The results from the studies, tradeoffs and analyses etc of the PrepSKA activities, will be utilised to support decisions regarding requirements development and design. The documents, reports, technical memo's and other information developed and gathered as part of this process will be collected and recorded in design files. These design files will be managed at all levels and the main custodians of these files will be the SPDO domain specialists (or project/system engineers in cases where SPDO is not taking the lead) who will ensure that these files are generated and kept up to date.

To guide the development of the human machine interfaces, including operators, maintainers and scientists a set of Operator Interface Control Documents (OICD) will be developed. These documents will provide guidance on screen layouts and operator interactions. Early development and review of these documents and mock-ups will ensure that the user community is involved right up front and will greatly support and guide the development of human machine interfaces.

The PrepSKA documentation 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 will have to 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 documentation 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 SPDO to be utilised throughout the project.

4.4.1.2 Repository[2]

A central repository for the project will be established and maintained by the SPDO. All documentation 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. This will enhance traceability and form a reference basis for any further work.

A documentation handling guideline and procedure has been developed by the SPDO to guide activities in this regard [10].

It will be the responsibility of the SPDO domain specialists (or project/system engineers in cases where SPDO is not taking the lead) to ensure that the documentation developed within their domain is submitted to the repository on a regular basis and especially before and after baseline reviews.

4.4.1.3 Engineering Baselines

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).

[2] Note that the word repository will be used throughout this document. It is, however, recognised that a comprehensive Configuration Management System and related Configuration Management Plan will have to be developed within the project (also see paragraph 6.9).

These baselines will progress from high level down to the lower levels but 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 more controlled. A more detailed description of the change management process can be found in paragraph 6.10.

To be able to successfully complete an engineering baseline, all the documentation as specified in this SEMP[3] will have to be presented during the review, reviewed, updated and submitted to the central repository. Failure to do so will result in a baseline being declared as not reached.

4.4.2 Phase 1

During Phase 1 it is foreseen that the work performed during PrepSKA will be taken further and the documentation utilised as the base for this work. Additional documentation will be developed and further life cycle baselines will be established down to the lowest level of the hierarchy.

Apart from the reviews several audits will be performed which will, in general, coincide with the technical reviews. Brief guidance on the audits is provided in paragraph 6.5.1.9.

All of the documents created and generated during Phase 1 will be controlled and be submitted at regular intervals to the SKA document repository.

4.4.3 Phase 2

During phase 2 it is foreseen that the design utilised during the Phase 1 roll-out will be refined and the production escalated to achieve the production capacities needed for Phase 2. Baselines will be updated and maintained very strictly during this phase.

All of the documents created and generated during Phase 2 will be controlled and be submitted at regular intervals to the SKA document repository.

4.5 Technical Objectives

The main technical objective of the PrepSKA WP2, as set out in [3] is:

> *"to produce a deployment plan for the full SKA, and a detailed costed system design for Phase 1 of the SKA"*

To achieve this it is important to realise that, as a subset of the full SKA, it will not be possible to design and cost Phase 1 without having a view on the full SKA design and cost.

In support of the PrepSKA WP2 objective a number of verification programs will be executed which are aimed at development of "standardised methods for verifying performance claims for key components" [3].

The intention of these verification programs is to reach a point where the applicability and feasibility of the relevant element or subsystem have been demonstrated and the design is captured to such a level as to be able to move forward into Phase 1 without major changes. Failure to reach this point may result in significant rework and delays to the overall project.

[3] 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.

The main aim of Phase 1 is firstly to refine the PrepSKA design documentation, build the first production units, develop the relevant software, integrate and perform standalone testing of these units, integrate all into a higher level and eventually roll out the entire Phase 1 instrument and relating support and people infrastructure on the selected site.

Depending on the progress and output from PrepSKA this strategy may change. This section of the document will therefore be updated as and when the strategy and philosophy of Phase 1 change.

4.6 Standards and Procedures

For the development of this document, two international system engineering standards were utilised as guidelines ([7] and [8]) as well as the Gamma-ray large area space telescope SEMP [9]. Although not prescribed for the SKA, it is highly recommended that both 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 PrepSKA the utilisation of other international standards and their applicability to the SKA will be investigated. Examples are:

- ISO software development standards (ISO/IEC 15288)
- 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 applicable to the project.

To aid in the alignment and coherency of the system engineering process, it is foreseen that a number of supplementary standards, philosophies and procedures will be developed internally to the project. Although not an exhaustive list it is foreseen that the following aspects will be included:

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

This list will be reviewed within the System Engineering Group for correctness and completeness and will be updated in accordance with the results of this review.

4.7 Constraints

Significant constraints in terms of time, focussed resources, the correct resources at the correct time, funding, technologies, to name but a few, are apparent, especially within the PrepSKA phase of the project. It is therefore recognised that it will not be possible to follow the full system engineering process as described in [7] and [8]. This SEMP therefore attempts to tailor this process to be able to focus on the important aspects and optimise documentation.

5 System Engineering Process and Application

5.1 Tailoring

Due to the constraints of time and resources faced, a tailoring of the process will be needed. Within this tailoring it is, however, not foreseen that steps within the process will be left out in their entirety, it merely implies that the scope and formal outputs of the process at each step may vary and that steps may be combined. The steps are important and skipping any one of them will result in a sub-optimal system design and poor value for money.

5.2 System Engineering Process

The system engineering process as defined in [7] is shown graphically in Figure 5 and it is proposed that this process be adopted and applied within the SKA project. In general each of the activities shown in Figure 5 will 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 by the Control Process (which will be described later in this document) and it will be difficult or close to impossible to skip any of the steps.

To streamline the process it is proposed that steps and baselines be combined. In this regard the requirements analysis and validation will be combined and the results will typically be reflected in the requirement specification.

The combination of the functional analysis, verification and synthesis will be captured in the relevant design documents while the documentation and data produced during the design verification will be captured in the design file.

Short descriptions of the steps of the system engineering process are given below.

5.2.1 User needs

To a certain extent the science user needs for the SKA user system are being captured in the Design Reference Mission (DRM). However, the scientists will not be the only ‘users’ of the system and it is foreseen that an analysis will have to be done in order to identify all the users (and stakeholders) of the system and to capture their needs. Translation of these needs into system requirements will be performed and will be flowed down the hierarchy to ensure influence on the design.

At each level of the hierarchy the user needs will have to be identified and formalised. To a large extent this will be in the form of the requirements allocated from the higher level and therefore this analysis will not be as extensive as at the user system and system levels.

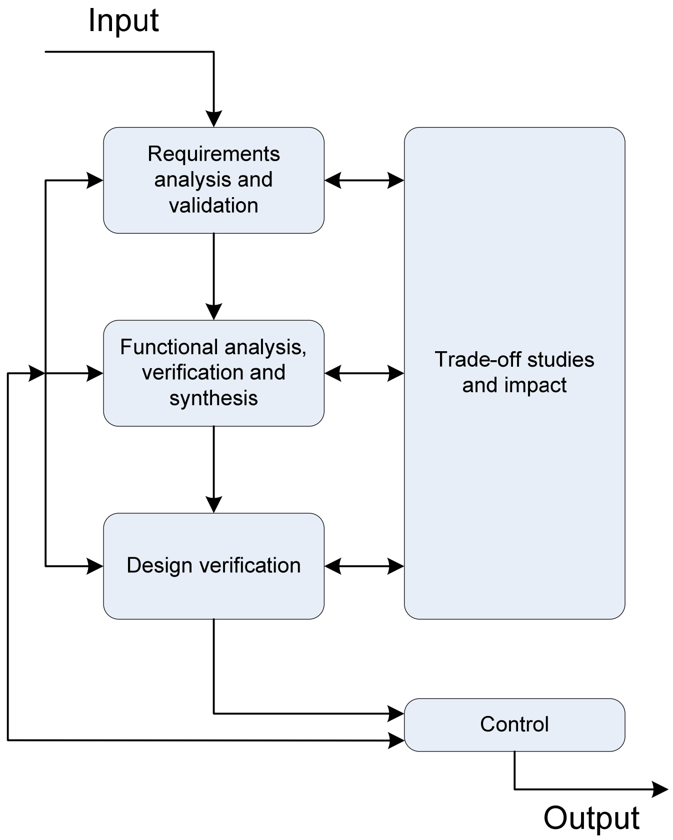

Figure 5: The systems engineering process**.**

5.2.2 Requirements Analysis and Validation

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 step.

Requirements on the system or any part of the system, in this case the SKA, do not stem from the science requirements of the telescope alone. The science requirements are but one aspect, albeit important, of the overall requirement space. To illustrate this point a first order context diagram of contributors to the requirements of the user system is shown in Figure 6.

From this diagram it can clearly be seen that contributions to the eventual complete set of requirements of the user system and all its parts include inputs from a large number of stakeholders and different aspects. All these aspects need to be considered during the requirements analysis and development to ensure that the telescope will meet its performance requirements over its lifetime, in the environment in which it is deployed, supported, operated and maintained.

A graphical representation of the requirements analysis process as contained in [7] is shown in Figure 7. The process is quite complex and include a large number of activities. It is not proposed to follow the process exactly as indicated but note should be taken of all the components of the process to ensure that no gaps are left during the execution of the process. Comparing the context diagram shown in Figure 6 with the requirements analysis process shown in Figure 7 shows very close similarities.

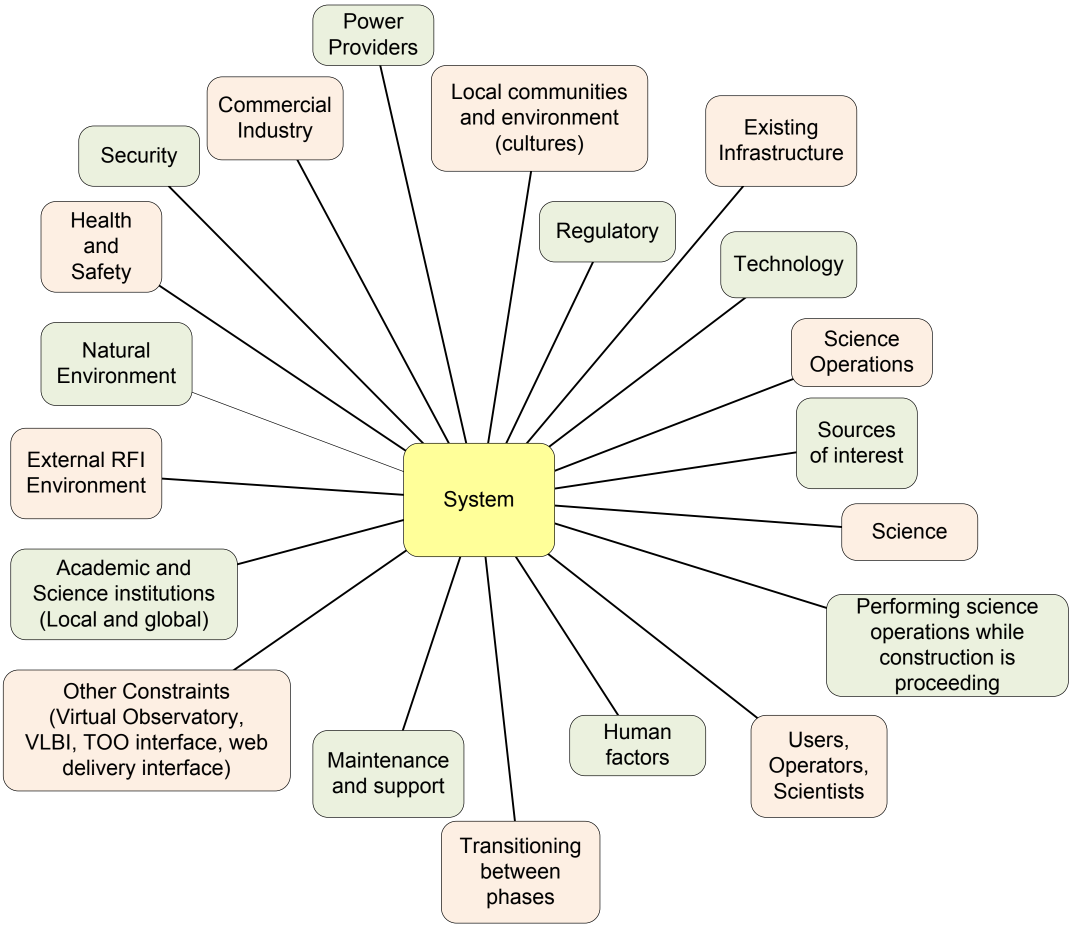

Figure 6: SKA user system context diagram**.**

Up to this point in time the requirements for the SKA have been driven by science requirements. This is not necessarily a bad thing but it is important that the identification and influence of the other aspects on the user system, and therefore the elements and subsystems, be initiated as soon as possible and that these requirements become visible to the lower levels early on. To accomplish this it is proposed that the context diagram be reviewed and refined within the System Engineering Group and that actions be identified to address the requirements development within each of the blocks in the context diagram. As a continuous process, the context diagram and actions will be compared to the flow indicated in Figure 7 to ensure that no gaps are left. A similar process will be followed at the lower levels of the project but to a large extent requirements will be allocated from the higher levels implying a less intense requirement analysis phase.

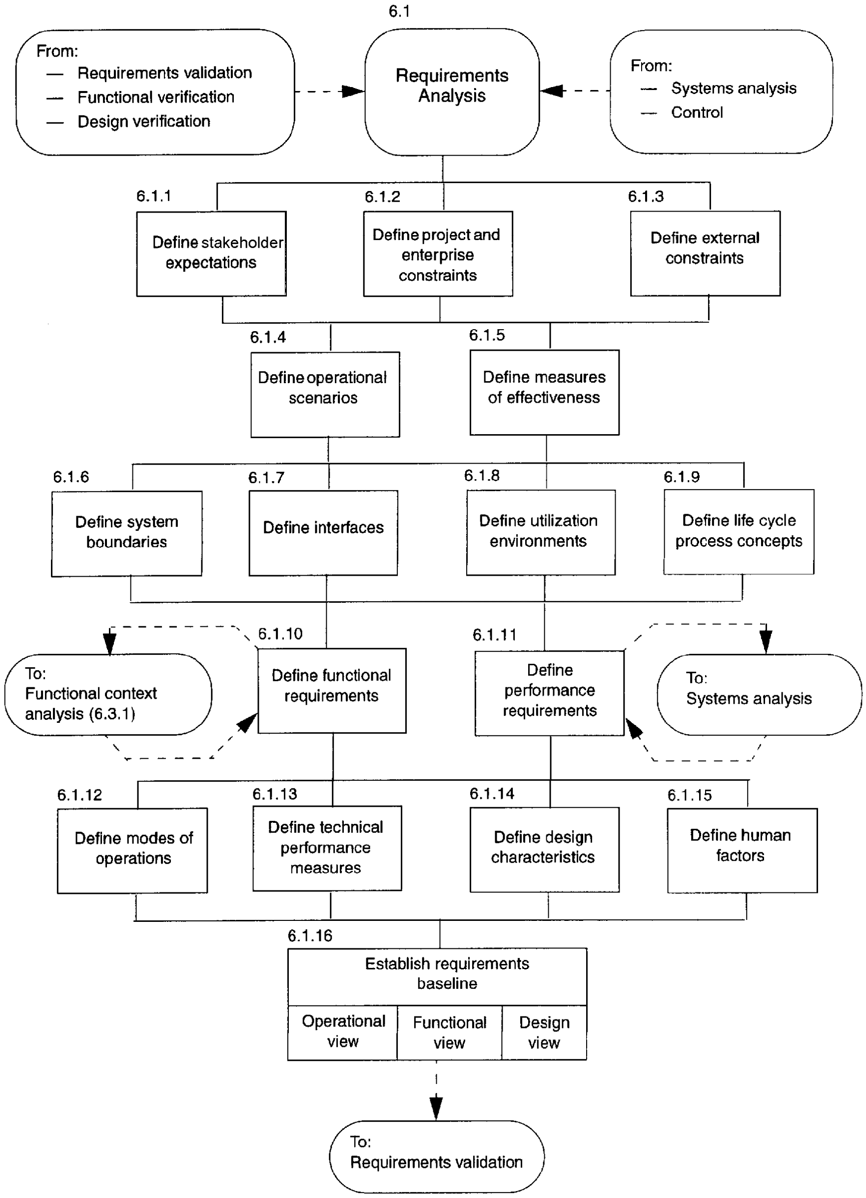

Figure 7: Requirements analysis process. Numbers refer to paragraphs in [7].

Input sources for the requirement gathering and analysis will include, amongst others, the outputs from WP3, Task Force activities, Working Group activities, the Science Operations Plan, the Support Plan, interaction with manufacturers and industry, interaction with other radio and optical telescopes, etc. It is foreseen that specific aspects may require the establishment of Task Forces to assist and address these aspects in more detail (for example the current Power Investigation Task Force).

Because the verification programs will be initiated before the user system level requirements gathering, analysis and validation phases have been completed, a subset of requirements will be allocated to each program as a starting point. 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 programs and precursor, design studies and other pathfinder arrays move forward they will provide feedback towards the user system and requirements will be adapted and refined aimed at maximising science return. At the same time the verification programs will be gathering, analysing and validating their own requirements for eventual recording in the relevant requirement specifications.

Requirements validation is the process whereby the requirements that have been developed are validated against the original stakeholder expectations, user requirements 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.

Throughout the process it will be important to record and write good requirements. A summary of good practice appears below.

5.2.3 Functional Analysis, Functional Verification and Synthesis

The three steps of functional analysis, functional verification and synthesis are in essence the work to be done to arrive at the architecture or the design.

Functional analysis is the first step in the design process. It describes the problem defined by the requirements in more detail and allocates functions and related perfomance to lower levels of the design. A graphical representation of the functional analysis process as contained in [7] is shown in Figure 8.

Each of the activities is important to ensure completeness of the process and the eventual design. The end result of this process will be a functional architecture that is subject to a functional verification aimed at confirming the functional architecture and completeness of the architecture.

Synthesis is the process whereby solutions for the functional architecture are investigated and elements and subsystems are identified. It translates the functional architecture into a design architecture. It is during this process that technologies and technology choices will play a role in the eventual design of the system (or element or subsystem). Other aspects such as the utilisation of off-the-shelf equipment and standardisation will also be addressed during this process.

To a very large extent the SKA elements and subsystems have already been defined and the design process is therefore not a blue sky search for design options. However, the functional analysis, verification and the allocation of these functions to the various elements and subsystems needs to be done to ensure that there are no gaps and that the elements and subsystems are able to perform the functions they are allocated. The combination of an already complete physical architecture and the combination of the three steps (functional analysis, verification and synthesis) will ensure that this part of the systems engineering process is as streamlined as possible.

Instruments to be utilised for the design process will include signal path analysis and block diagrams.

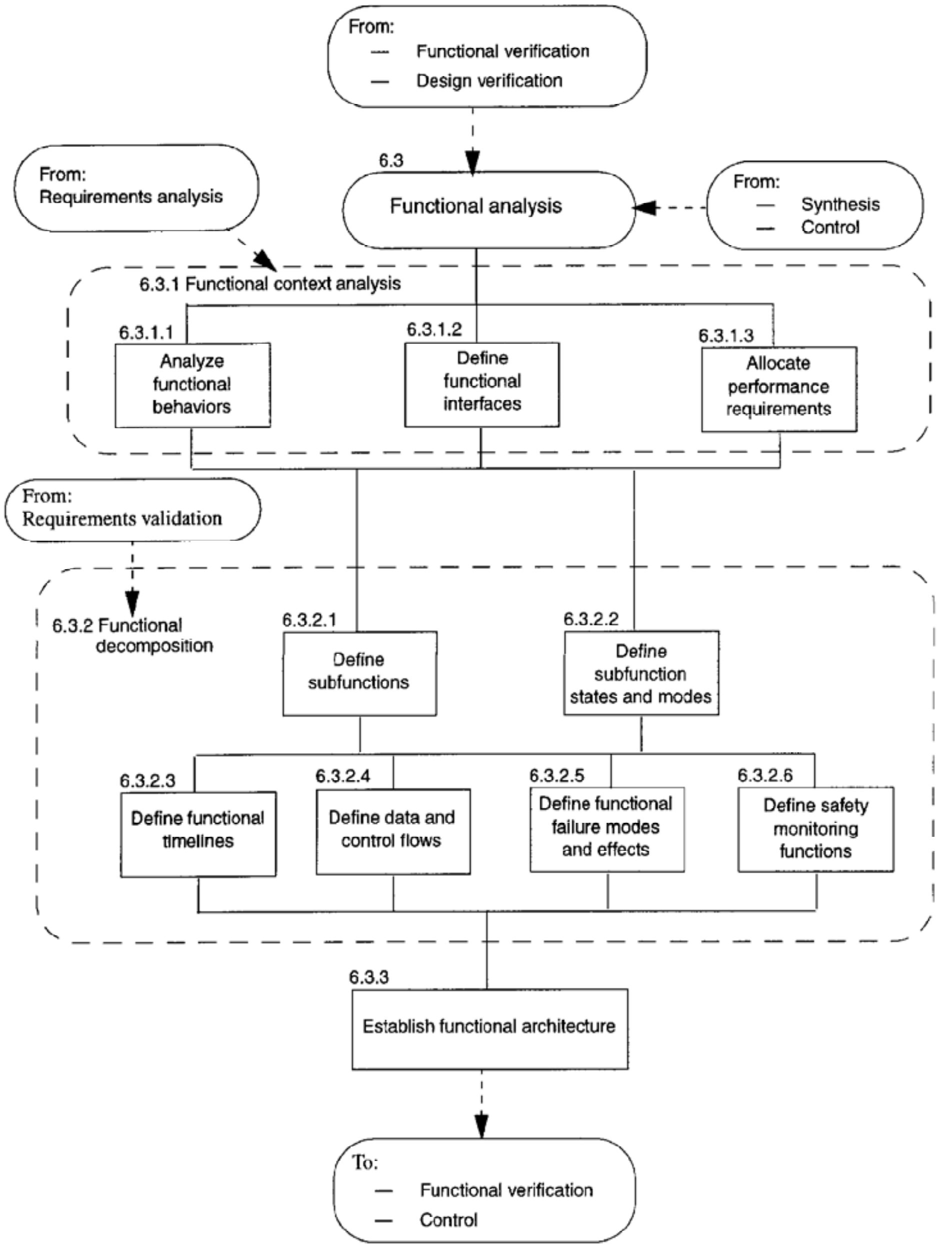

Figure 8: Functional analysis process. Paragraph numbers are from [7]**.**

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

5.2.4 Design Verification

As indicated in [9] 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 probably being the most dominant criterion. However, care must be exercised when performing cost trade-offs because it will be important to ensure that "apples against apples" trade-offs be done, and that all aspects of the life cycle are included in the cost before using it as a parameter in trade-offs. Aspects such as 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 spend more money up front 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. However to accomplish this, a view on the SKA design will have to be taken early on as well. In this regard a number of studies and analysis have already been conducted 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 user system level, in which large elements or subsystems will be involved. Decisions in these cases will not be feasible because of the multi dimensionality of the problem and for these major decisions sound a decision making process has been developed [5].

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/subsystem which may imply that COTS equipment has to be modified before it can be used in the project.

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

Further detail and guidance on trade-offs in the context of SKA can be found in paragraph 13 of [3].

5.3 Application of the System Engineering Process

The high level life cycle phases that will be adopted for the SKA project are shown in Figure 9. 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. Note that Figure 9 is not intended to provide an indication of the duration of each phase but does provide insight on which of the phases has to be completed within the overall project and system phases.

A more detailed breakdown of the phases at system, element and subsystem level as well as the proposed alignment of the technical reviews is shown in Figure 10. In general, a design review will be conducted and a baseline established at the end of each phase. Within each element and subsystem there will be a further breakdown, not shown in Figure 10, whereby the same system engineering process and phases are followed to define, design and build these elements and subsystems.

The breakdown as shown in Figure 10 is a first order draft high level breakdown up to and including Phase 1 and will need further review and refinement especially in the software and digital domains. Important to note is that all the elements and subsystems have to be completed, delivered to site, integrated and tested before the last part of the user system verification and commissioning can be completed and the user system accepted.

An additional phase (system refinement) has been added at user system level. This is not a systems engineering phase as such but has been added to indicate that the user system level work and interaction with the lower levels will continue throughout the life cycle of the project.

Figure 10 focuses only on PrepSKA and Phase 1 activities and provides a more detailed view of the system engineering activities during these phases compared to the detail provided in Figure 1. As the project moves forward and the picture becomes clearer the detailed planning for Phase 2 will be added.

Each of the phases indicated in Figure 10 is described in more detail in paragraph 5.3.1.

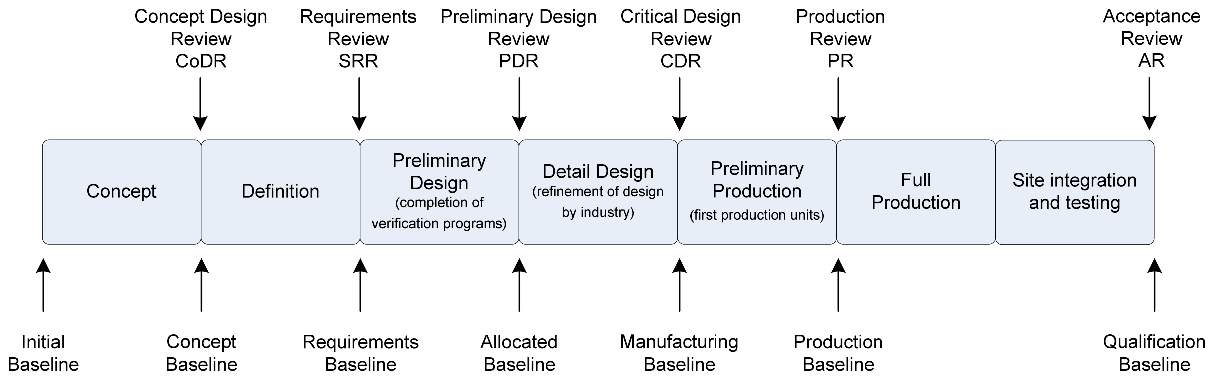

Figure 9: System engineering phases, reviews and baselines**.**

Within Memo 100 [2] (chapter 11) a number of high level milestones and reviews have been identified. These reviews do not correspond fully in terminology with the reviews and phases described in this document. The proposed alignment of the Memo 100 reviews with the user system reviews of Figure 10 is:

Memo 100 Review	System Level Review
• Publication of Phase 1 and SKA preliminary specifications	CoDR
• Phase 1 first design review	PDR
• Wide field of view first design review	PDR
• Publication of SKA final specifications	CDR
• Phase 1 second design review	CDR
• Wide field of view second design review	CDR
• Production readiness review for SKA mid and low	Done at element and subsystem level
• Top level specifications for SKA high-band array	To be planned

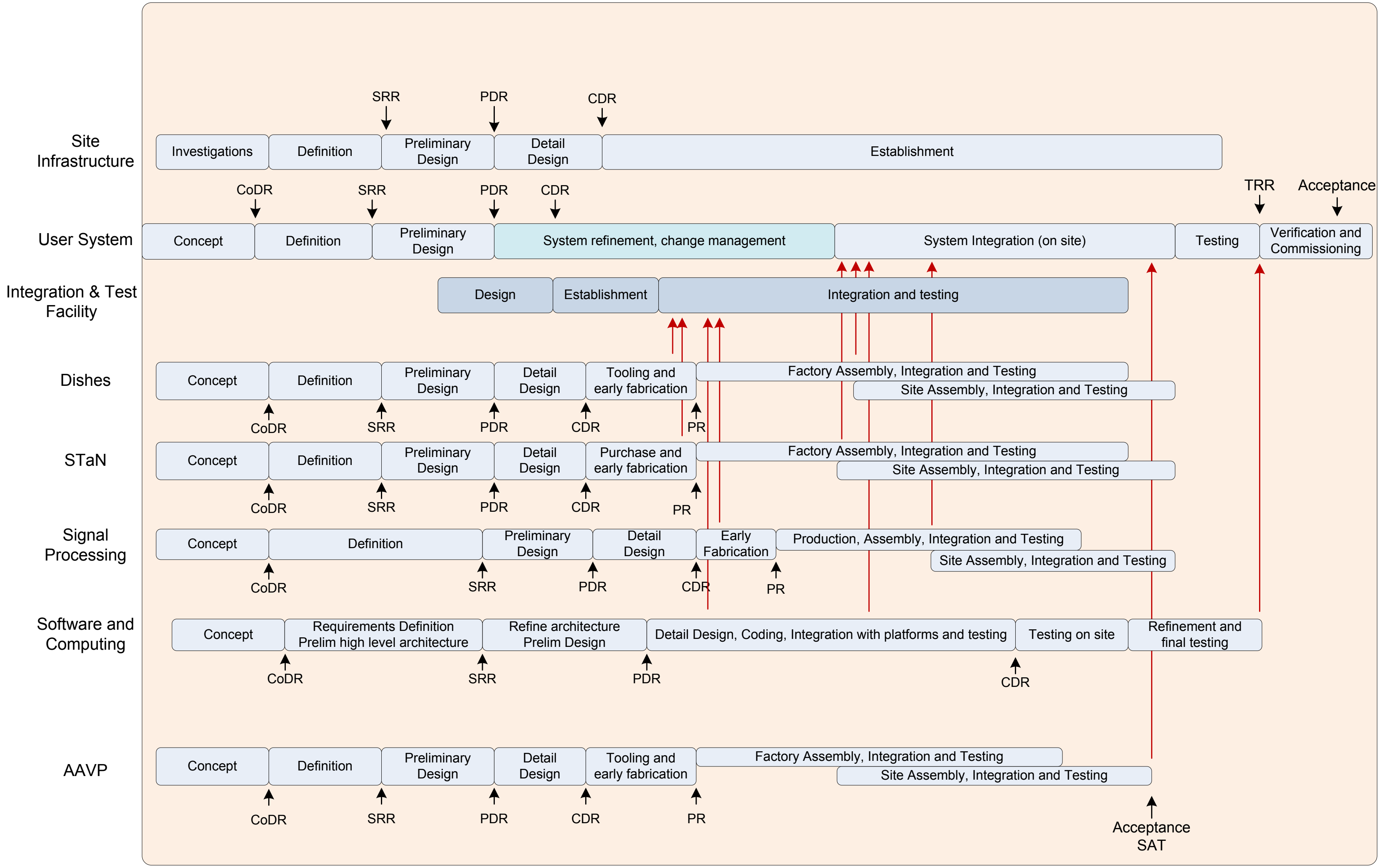

Figure 10: SKA1 typical system life cycle phases and reviews.

5.3.1 Systems Engineering Phases and Engineering Baselines of the SKA

The system engineering phases and related design reviews and baselines as adopted for the project are show in Figure 9.

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.

Engineering baselines will be achieved once the relevant design review has successfully been completed. A baseline is therefore a full set of documents describing the system/element/subsystem 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

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 Memo 100 [2] and various other memos. A solid base has therefore been established and work can now continue into the definition phase.

The concept phase is 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 subsystem (as applicable).

The concept phase will be concluded by the Conceptual Design Review (CoDR). The Concept Baseline is reached upon conclusion of the CoDR.

5.3.1.2 Definition Phase

The aim of the definition phase is primarily to perform requirements analysis and validation to ensure that the complete set of requirements is understood and is present. 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.

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 subsystems 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 will also be initiated with the aim of producing a first draft design document at the end of the phase.

Interfaces will be refined and finalised as far as possible (especially functional interfaces).

This phase will be concluded by the (Sub)System Requirements Review (SRR). The Requirements Baseline is reached upon conclusion of the SRR.

5.3.1.3 Preliminary Design Phase

During this phase the candidate technical solution(s) selected at the end of the definition phase will be refined and final 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 programs).

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

This phase will be concluded by the Preliminary Design Review (PDR). The Allocated Baseline is reached upon conclusion of the PDR.

With one or two exceptions the elements and subsystems will achieve the completion of the preliminary design phase at this point. It will be important that the reviews at lower level be conducted before the final PDR at system level. The results and underpinning documents generated at element and subsystem levels will form the base for the finalisation of the system preliminary design phase. This is not in accordance with the classic systems engineering approach where lower level reviews typically follow after the conclusion of similar reviews at higher level. However, to ensure that the user system level reaches the optimum maturity level, the process is being changed as described. This will require 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.

A graphical summary of the narrowing down of the technology options within the three phases described thus far is shown in Figure 11. The aim should be to narrow down the options to one low risk baseline technology option to be confirmed at PDR. Carrying more than one option beyond this point will increase risk, 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. Also note that the process as depicted in Figure 11 is applicable to all the hierarchical levels of the project.

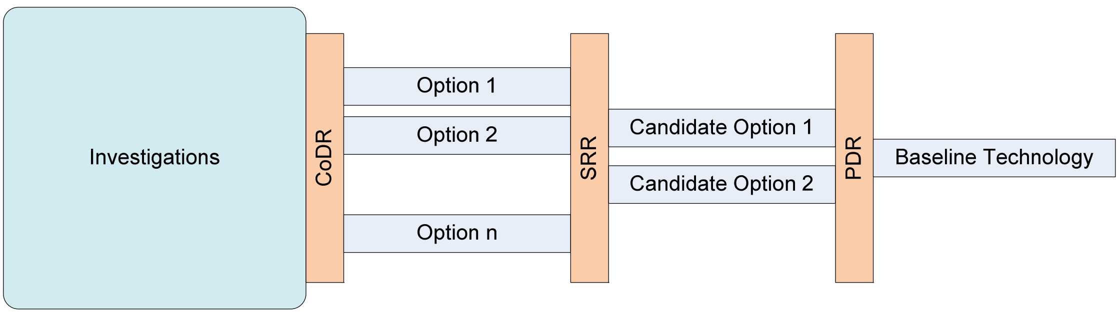

Figure 11: Narrowing of options during first three phases**.**

5.3.1.4 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. Ideally this will imply only minor updates and modifications to the already 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 subsystems 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 testing[4] of assemblies and subassemblies will be completed.

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

5.3.1.5 Production

During the two production phases, assemblies and subassemblies are manufactured, in accordance with the detailed designs produced during the previous phase, at various facilities. These assemblies 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.

Assembly, Integration and Testing

During this phase, subsystems 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 requirement specifications. Tools to be used include emulators, simulators and mechanical test jigs and templates.

With the integration and testing completed, the element or subsystem 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 subsystem is ready for formal verification testing.

Verification

During this phase, the subsystem 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 subsystem against its design and requirement specification and external interfaces prior to delivering the first subsystems 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 qualification[5] tests, logistics tests and other tests already performed, will be presented to prove compliance of the subsystem to the

[4] It is strongly advised that Qualification Test Procedures be kept separate from functional Acceptance Test Procedures.

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

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.

5.3.1.6 Site Integration and Testing

Site assembly, Integration and Testing

Once on site the subsystems will be installed and set to work in a stand alone 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 subsystem.

This phase is more complex than it might seem because in some cases subsystems might need the support of other subsystems to be able to complete the SAT. Simple examples are power and cooling. Careful planning of the on site roll out will therefore be needed.

System Integration, Verification and Acceptance

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

Depending on the eventual design and configuration of the Phase 1 telescope it is foreseen that the subsystems 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 will be possible.

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

Commissioning and Validation

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

It is important to note the difference between verification and validation. Verification (and the related acceptance) is an engineering milestone while the validation (and related commissioning) is aimed at establishing the science performance of the Observatory. The reason for the split lies within the work done at the start of the project when science is translated into engineering specifications. Verification is therefore aimed at proving that the system complies with these engineering requirements (have we built the thing right) while validation is evaluating the system against the user (science) requirements (have we built the right thing).

No formal review is foreseen but at some stage the Phase 1 instrument will be handed over from the engineering team to the science team for utilisation.

5.3.2 Notes

A few aspects woven into all of the phases above and which need more clarity are now described in more detail.

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.

Testing should be addressed and be brought into the systems engineering process from very early on. Ideally the requirement specification and the first high level test plan should be developed simultaneously. It will enhance the quality of requirements by ensuring that each one will in fact be testable. The requirement specification does include a section showing the cross verification between requirements and the kind and type of tests to be performed to prove compliance with each of the requirements.

The first subsystems, also called the first articles, to be delivered to Phase 1 will be thoroughly tested, audited and acceptance tests will be 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 via similarity.

The establishment of integration and test facilities for major subsystems and elements away from the site will be investigated. These facilities are invaluable and will iron out integration issues and ensure that the subsystems that follow can be integrated on site with much more ease. These facilities can also be used as reference systems to implement, test and verify changes that might be necessary before these changes are rolled out on site. A graphical representation of the process to be followed utilising these kinds of facilities is shown in Figure 12.

Ideally the first article tested during the FAT will remain in the factory environment. The next few production units, updated to the status achieved at the end of the FAT, will be deployed in the integration facility. Testing will be done and results fed back to the manufacturing process before large scale production of subsystems will commence. The first articles in the factory and first subsystems in the integration facility will be reworked to final production status towards the end of the site roll out.

The scope of the rework will depend on the testing that has been performed on the assemblies of each of these subsystems. For example – some of the assemblies of the subsystem in the factory may have been subjected to intense environmental qualification. This will almost certainly have an adverse influence on the expected lifespan of the assembly. In many cases it will be cheaper to manufacture a new assembly as part of the production process and not to rework the qualification units. However, all these aspects will have to be considered as part of the rework strategy.

All acceptances will be performed against approved acceptance test procedures (ATPs) only so it is important that acceptance documents be developed, reviewed and approved as early as possible. 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 subsystems 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 EMC testing program will be conducted at various levels of the project to ensure compliance of equipment, both stand alone and integrated, to project EMC 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.

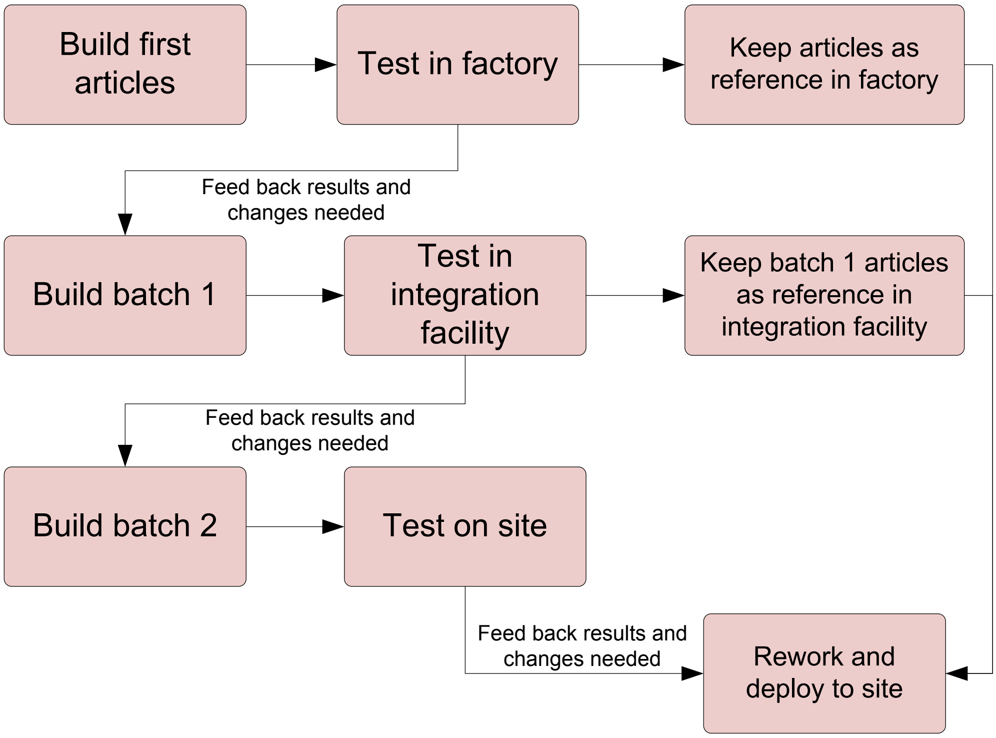

Figure 12: Roll out utilising integration test facilities**.**

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, Production Engineering & Tooling phase.

5.3.2.2 Software

The development of software during the project needs careful consideration. In this regard, the SPDO software and computing domain specialist will develop 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 subsystems, 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 with a similar development approach and development phases as described in paragraph 5.3.1. In this regard a Logistics Engineering Management Plan (LEMP) will be developed (see paragraph 6.11 for more detail)

5.3.2.4 Operations

A key element and a major influence on the requirements at user system level is the Science Operations Plan for the instrument. Work on this plan will have to start soon to ensure that requirements are gathered and the design influenced to the extent required.

5.3.2.5 Phase 2

Phase 2 activities will be initiated before the conclusion of Phase 1. 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 Control

To ensure that the systems engineering effort remains on track, a number of control mechanisms will be adhered to. These measures are described in more detail below.

6.1 Project Dictionary

To be able to 'speak the same language', a project dictionary will be developed. To enhance communication and avoid confusion and assumptions, the dictionary will be applicable to all parts of the project. SPDO domain specialists and other project and/or system engineers will ensure that terminology used within their domains comply with the project dictionary at all times.

A first draft dictionary will be developed by the SPDO systems engineer and will be published for review by the systems engineering group. Following the review the dictionary will be updated and be maintained by the SPDO.

6.2 Work Breakdown Structures

To ensure that all bases are covered, a work breakdown structure (WBS) will be developed. As a first step the WBS developed and agreed to for the WP2 and WP3 work packages will be reviewed for completeness and alignment with this SEMP. Wherever additional WBS for the user system and element level exist, these will be reviewed for completeness and alignment with this SEMP as well. In cases where no WBS exists, parties will be identified to develop the specific WBS. The final output will be a consolidated, complete (as far as possible at this stage) and aligned WBS. It is not foreseen to be a very detailed WBS at the outset but as PrepSKA moves forward, the WBS will regularly be revised and refined.

The WBS will include descriptions of the work to be performed, the responsibilities and the expected deliverables. The WBS will furthermore be linked with the system hierarchy as described in paragraph 4.3.

6.3 Interface Management

Interface definition and management will be one of the key aspects underpinning the project. During the initial phases of the project, interfaces will be identified and high level requirements will be captured in the requirements specifications. This will be followed by the development of separate documents for the interfaces and as the design of each particular piece of equipment progresses, the interfaces will be refined. These documents will exist on all levels of the project with varying degrees of detail and will include mechanical, functional, data and electrical aspects.

A high level interface register will be compiled and maintained at user system level by the SPDO. Within this register the owners, the parties involved, and the type of interface will be identified. It is not the intention that this register includes all the interface control documents for the project, a similar concept will be deployed at element and subsystem level (at least).

The 'owner' of an interface will be the party that leads the development and eventual agreement of the Interface Control Document (ICD). The owner will also ensure that rigorous configuration control be exercised on the document once signed. At no stage can one party (including the owner) change/modify an interface without the approval of all parties affected by the change including of the relevant systems engineer or SPDO domain specialist.

ICDs must be clear and unambiguous and thorough review and discussion of each document will be essential.

6.4 Data Management

The data generated during the project will be captured within the design files (as described in paragraph 4.4.1.1) 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 and for both WP2 and WP3 activities of the project a series of design reviews will be conducted, each aimed at the establishment and confirmation of the appropriate baseline of the particular aspect/equipment under review. To a large extent these baselines will be established in a top down fashion, with the baseline of the higher level serving as an input for the work and finalisation of the baselines at the next lower level.

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 relevant SPDO domain specialist or system engineer who will oversee the process and make sure it complies to the guidelines set out in this document.

The following reviews have been identified as part of PrepSKA and Phase 1:

- Conceptual Design Review (CoDR)
- (Sub)System Requirements Review (SRR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Production Review (PR)
- Test Readiness Review (TRR) (not shown on diagrams)
- Acceptance Review (AR)

The phasing and timing of each of these reviews for each domain are shown in Figure 10 and for the longer term in Figure 1.

Ideally any review will be conducted by releasing all the relevant documentation before the review, with the actual review being conducted as one event stretching over a number of days. However, in exceptional cases it will be possible to conduct reviews in a phased manner as and when the required results and documents become available. These phased reviews should not be a drawn out processes stretching over 'unlimited' timeframes, and all attempts must be made to initiate, conduct and complete the design review in the shortest possible time.

The effort to conduct high quality and relevant reviews should not be underestimated. Performing diluted reviews based on a variety of poor excuses must be guarded against. The time to influence the design is in the early stages of the project and the one way to ensure that this is done is by conducting proper reviews.

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

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 to unit level.

The review purpose, mandate and documentation vary for the specific phase or stage of activity 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

Initiation of the review

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

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.

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 in Observation Action Register (OAR) worksheets.

OAR files are a collection of comments from a single reviewer broken down by document.

Collocation meetings between the review team and the SKA Project/Community serve to solve issues raised in OARs, 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 Board.

The information flow for this review activity is illustrated in Figure 13.

An example of a logic diagram for the OAR processing is presented in Figure 14.

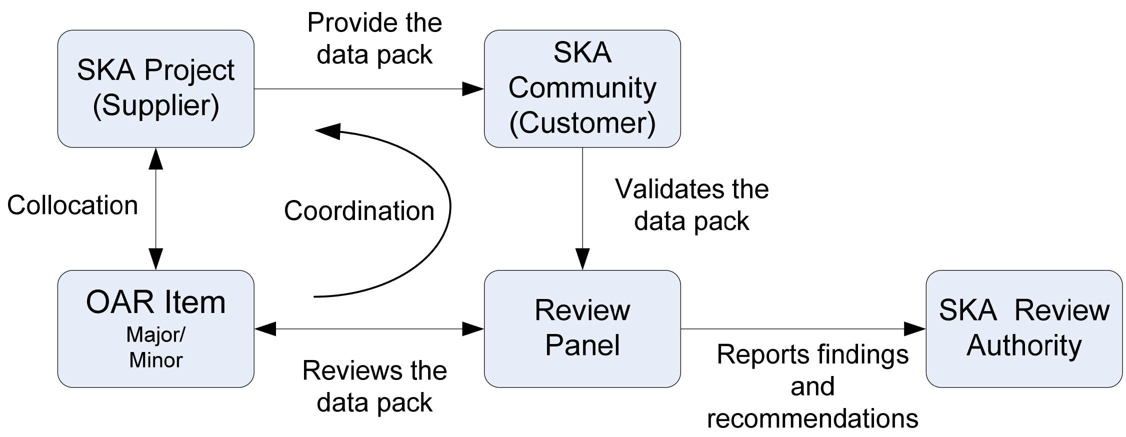

Figure 13: Review information flow

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.

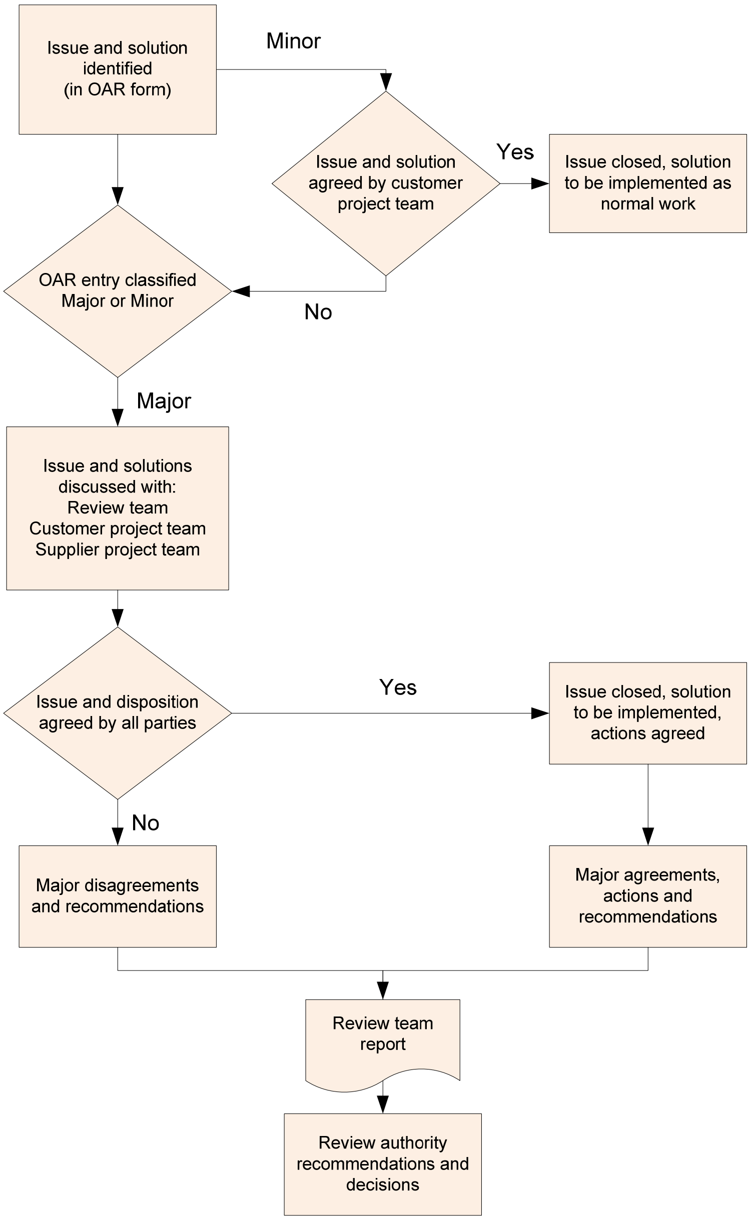

Figure 14: OAR Worksheet processing

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.

Apart from the control aspects (described in paragraph 6) some cross cutting influences will need focus from early on and will be discussed at each review. These include:

- Power requirements
- Cooling requirements
- EMC (RFI)

- Costs
- Reliability, availability and maintainability (RAM)
- Quality
- Health and safety

Although not exhaustive the list above is to serve as a reminder to all to include discussions on these aspects if not addressed as part of the review itself.

6.5.1.4 Concept Design Review (CoDR)

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 subsystem
- 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
- Technology roadmaps (where applicable)
- Descriptions of implementation options

6.5.1.5 (Sub)System Requirements Review (SRR)

The SRR, conducted at the end of the definition phase, will review primarily the definition of the specific building item[6] 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:

- 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 subsystem
- First draft interface control documents (internal and external)
- First draft acceptance test 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, power 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

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

- 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
- Upgrade plans
- Roll out/build plans
- Logistic Engineering Standards & Procedures
- Audit of manufacturing datapacks for designs to be carried forward
- 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, power, reliability etc.
- Review of integration and test plans

The exact details of this phase will be developed and expanded during PrepSKA.

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 requirements 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 find their way down to the lower levels via the user system level and 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 files 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 [9].

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.

To accomplish this, a comprehensive requirements tracking database will have to be established. Although there are numerous tools commercially available to accomplish this task they are quite expensive. The SPDO system engineer will conduct a review of the available tools for selection of the tool most appropriate to this phase of the project. Until this activity has been completed the process will use standard office productivity tools.

To facilitate traceability each of the requirements recorded in the relevant requirement specifications will each be allocated a unique identifier. Guidance in this regard will be developed by the SPDO system engineer.

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 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 again. In the event of the latter, the requirement needs to be rolled back up to ensure completeness of the requirements at the higher level.

6.7 Risk Management

As a high technology project with a large research component, the SKA faces many risk areas. A comprehensive risk management program will be established as soon as possible and be maintained throughout the life cycle of the project.

A separate Risk Management Plan has been developed by the SPDO to guide the work in this regard [6].

The risk management program will be established at all levels and within all domains of the project. It will be the responsibility of the various SPDO domain specialists and other system engineers to establish and maintain the risk management program within their domain.

Design reviews and progress meetings will be utilised as opportunities to review and assess the risk status of the particular domain.

6.8 Baseline establishment

The early development of the SKA presents an astronomical number of degrees of freedom, trade spaces and technology evolution processes. Whilst striving for the highest performance and best value for money, requirements must be eventually stabilised and designs finally frozen.

System engineering offers techniques to manage the process and to retain design flexibility for as long as possible. These involve the intelligent establishment of baselines, both in requirements and the associated design. Changes are then managed incrementally to these baselines.

Baselines are subject to major and minor change, with changes made with careful timing. Of first order consideration is the time allowed for analysing proposed change. Reviews are conducted against this background, with each review confirming an appropriately analysed baseline both in requirements and design terms.

The purposes of SKA reviews are discussed above. It is therefore possible to outline a baseline establishment strategy threading these reviews.

At System CoDR, a design baseline is described in terms of an architecture, a configuration and some enabling technologies, both in development within the SKA programme and mature. Additionally, projections are made regarding the availability of future technology whose development is outside the control of the SKA community. This baseline is derived from a necessarily incomplete analysis of a necessarily incomplete requirements set. This baseline itself therefore incomplete. The CoDR is concerned principally with the problems of this baseline and how they are to be addressed. Following this Review, two processes of development (‘change’) will take place, namely requirements definition/change/refinement and the design response.

The Domain CoDRs follow, conducted inevitably in an environment of steady change which must be controlled. The boundary conditions (upper level requirements, system architecture, system configuration and a concept of operations) must be stable if the benefits of Domain level review are to be gained. Stability and improving definition are more important than absolute correctness, which has been maximised at the time of System CoDR.

It is for this reason that the Domains that are closely coupled to the system must be reviewed at Concept level as soon as possible because the Concept review stage has a certain inhibitory effect on design progression. Furthermore, change control of the boundary conditions used for System and Domain reviews becomes subsequently vital.

It is proposed that

6.9 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, the configuration management program will also include the management, control and release processes for hardware, firmware, FPGA/ASIC designs (gateware) and software.

Configuration management include:

- Document numbering and version control including 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 gateware 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. This will primarily be part of Phase 1 activities.

A configuration management system is clearly more than just a repository and it may prove to be necessary, even during PrepSKA, to establish a more formal Configuration Management System in contrast to the document repository as described in 4.4.1.2. However, until such time and because the initial stages of PrepSKA are documentation driven, guidance for the management of documentation will be provided in the documentation handling guideline [10].

A comprehensive configuration management system and configuration management plan will, however, have to be established and developed within the next phase of the project.

6.10 Change Management

Change management will make sure that baselines are maintained and up to date at all times. It is the process whereby items including documents, hardware and software, can be changed, updated or modified once they are part of a baseline.

The purpose of the process is to ensure that:

a) A change is needed

b) The proposed change and its impact on the project as a whole is thoroughly assessed

c) The change is communicated to all affected parties

d) The change is implemented as agreed

e) The change, once implemented, is thoroughly verified and closed

As the project progresses, the process of implementing change will become more complex. During these phases a distinction will be made between two classes of change proposals namely Class 1 and Class 2. Class 1 changes will have an impact on other elements or subsystems within the project while Class 2 changes will be limited to the item itself.

Prior to the establishment of a baseline the updating and changing of items will not be controlled formally. However, good engineering practice will be exercised at all times to eliminate confusion and rework. As soon as a baseline has been established, be it the signing of a specification or interface control document or the official first release of software, the more formal change management process will be applicable.

6.11 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 [11]. Within this plan the following concepts has 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

Although all aspects will not be applicable to PrepSKA, they will all be applicable to the eventual Phase 1 instrument and need to be addressed early.

6.12 Quality

Quality and the ability to bring high quality as low costs into the project will be one of the keys to the eventual success of the project. The SKA will be built on a remote and “hostile” site requiring high quality of workmanship and equipment to be able to operate and survive for the lifetime of the telescope. Quality must therefore be at the forefront of all the activities, and component and part selections that are going to be performed early on in the project.

Quality during PrepSKA will not only be focussed on the documentation that will be produced because in a few cases components will be selected as part of the design process. The temptation might be to select the cheaper option components to bring down the manufacturing costs but in many cases this philosophy will lead to potentially very expensive reworks and refits. Selection of the most expensive component may also not solve the problem and it will be the selection of the right component that will make the difference.

It is not foreseen that an independent quality assurance entity will be established within the project during PrepSKA. The responsibility will therefore be with the SPDO domain specialists and other relevant system engineers to ensure the quality of designs foreseen to be carried forward into Phase 1. It is proposed that a set of guidelines be developed as part of PrepSKA and utilised during the final reviews at the end of PrepSKA.

Quality aspects will form part of the technical reviews, and risks that are being faced due to quality issues will be recorded and managed via the risk registers.

Wherever possible the verification of the advertised “quality aspects” of components needs to be verified. This need not be expensive quality testing, and other methods such as interaction with industry, other users and other radio astronomy projects will prove invaluable.

For Phase 1 a quality assurance capability and capacity will have to be established. In this regard a Quality Assurance Plan will be developed as part of PrepSKA addressing the quality aspects for Phases 1 and 2 of the SKA.

Software quality aspects will be addressed in the Software Standards to be developed by the SPDO domain specialist.

7 Transitioning High Risk Technologies

In support of the main PrepSKA deliverable, 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 PrepSKA.

A typical technology transitioning and decision making process is shown in Figure 15. At the first decision point the options will be subjected to the decision making process. The result of this process will identify the baseline technologies to be carried forward to the final baseline design for the SKA.

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.

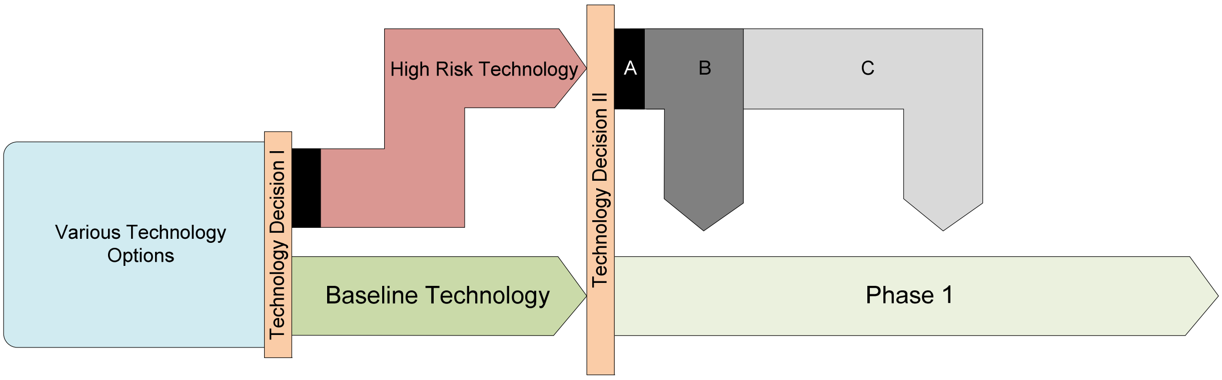

Figure 15: Technology decision points**.**

This strategy has been adopted with the establishment of the Advanced Instrumentation Program (AIP). The baseline technology for SKA1 has been selected and the decision points identified as 2013 and 2016 (see [12] and [13] for more details)

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.

Although the risk exposure has been significantly reduced due to the selection of the SKA1 front end technologies, several risks remain and will require a risk management program to be initiated as soon as possible. As a starting point the highest risk areas to be addressed as part of the verification programs have to be identified and the strategies within these programs to address these risks need to be developed.

A decision making process has been developed and was reviewed extensively. The process is aimed at the trade-off of technologies against a variety of metrics (including cost) to achieve maximum science return at any given point in the project. Refer to [5] for more detail.

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.

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 program. Guidelines in this regard will be developed by the SPDO system engineer and will eventually be the responsibility of the SPDO domain specialists and other systems engineers to implement within their domains.

8.4 Obsolescence

Because technology choices will have to be made quite 'early' during PrepSKA, 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 SPDO domain specialists 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 PrepSKA phase attention will have to be paid to the human engineering aspects. The scope and depth of this work still have to be established but it is foreseen that the work will have to be completed during PrepSKA.

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 PrepSKA 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.

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