CONCEPT OF OPERATIONS FOR THE SKA OBSERVATORY

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DOCUMENT HISTORY

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LIST OF ABBREVIATIONS

ALMA............................Atacama Large Millimetre/submillimetre Array
ConOps.........................Concept of Operations
GHQ..............................Global Headquarters
HCHQ............................Host Country Headquarters
HST...............................Hubble Space Telescope
KSP...............................Key Science Project
OCD..............................Operational Concept Document
PI..................................Principal Investigator
RFI................................Radio-Frequency Interference
RSEC............................Regional Science and Engineering Centre
SKA...............................Square Kilometre Array
VLBI..............................Very Long Baseline Interferometry
VLT................................Very Large Telescope

1 Purpose and Scope of the Document

The *Concept of Operations for the SKA Observatory (ConOps)*, has two purposes:

a) To define the SKA operational model in a way that operational requirements on the design of the SKA can be obtained. The ConOps complements the science-based description of *what* the SKA is intended to achieve by describing *how*, from an organisational perspective, this is to be done.

b) To communicate the top-level model, including science and operational policies and design, to stakeholders such as scientists and funding agencies.

The scope of the ConOps is the entire SKA Observatory.

This document first summarises the scientific purpose and scope of the SKA Observatory and outlines how its scientific projects will be conducted. It then describes the required top-level (operational) functionality. The relationship of the operational organisation to the construction project is outlined.

The current document replaces *SKA Operational Concepts* [RD1]. It is intended to be consistent with (and governed by) the principles and decisions of the SKA Board including the Top-level Principles of the Concept of Operations [RD2]. Requirements generated from this document will be maintained in the SKA Level 1 Requirements document.

2 References

2.1 Reference Documents

The following documents are referenced in this document.

- [RD1] SKA Operational Concepts, P.E. Dewdney, WP2-001.010.010-PLA-002, February 2011
- [RD2] Top-level Principles of the Concept of Operations, P.J. Diamond, SKA-BD-10-13, July 2013 (as amended June 2014)
- [RD3] A model for the first SKA1 Key Science Projects, D. Bock et al., SKA-BD-15-22, October 2014
- [RD4] Principles of Access Policy, S. Berry, SKA-BD-13-06, May 2014

3 Purpose and Scope of the SKA Observatory

The Square Kilometre Array (SKA) will be the world's largest telescope in the cm-to-m range of wavelengths, built to greatly surpass the current generation of telescopes in sensitivity and fields of view, and with sufficient resolution to address the foremost questions in astrophysics that are likely to dominate the field in the next generation. The international community has developed a set of Key Science Programs[1] of the SKA:

- Galaxy Evolution and Cosmology
- Tests of Strong-field Gravity with Pulsars and Black-Holes
- Cosmic Magnetism
- Cradle of Life
- Dark Ages and the Epoch of Re-ionization.

In addition to the programs listed, and recognizing the long history of discovery at radio wavelengths (pulsars, cosmic microwave background, quasars, masers, the first extra-solar planets, etc.), the international science community also recommended that the design and development of the SKA have "Exploration of the Unknown" as a philosophy. The telescope will be designed in a manner to affordably allow flexibility and evolution of its capabilities to probe new parameter space (e.g., time-variable phenomena that current telescopes are not well-equipped to detect).

The purpose of the SKA Observatory will be to enable scientists to pursue world-leading scientific programmes, to organise and conduct improvements and upgrades of the SKA telescopes in order to provide and maintain facilities that are at the forefront of science and technology and to ensure the protection of the SKA sites for the SKA and future radio telescopes.

3.1 SKA Telescopes

An *SKA Telescope* is defined as a single scientific instrument of the SKA that can operate as a coherent system independently of other telescopes, but which may share resources, including software, with other telescopes. Each telescope will include the necessary hardware (including data storage) and software to produce quality controlled data products capable of being distributed to users.

3.2 The SKA Observatory

The SKA Observatory will consist of SKA Telescopes, local activities necessary for their operation, data processing and archive facilities and a Global Headquarters. The Observatory will be operated as a single organization led by a Director-General reporting to the SKA Board of Directors. Its expected lifetime is 50 years.

The SKA Observatory shall operate a Global Headquarters (GHQ), which will have overall responsibility for the SKA Observatory, and shall establish a presence in the two Host Countries for the purpose of controlling SKA infrastructure[2] and conducting SKA Operations in the Host Countries. The scope of the SKA Observatory will be to provide, commission, maintain, and upgrade the SKA Telescopes, and to deliver, support and curate scientifically viable data from the telescopes. The SKA Observatory will be the technical design authority for the SKA Telescopes during both construction and operations. The SKA Board shall appoint an external body to provide independent advice to the Director-General on

[1] *We note a change in nomenclature here. The Key Science Programs describe the overarching scientific goals of the observatory, and were previously called Key Science Projects. The actual Key Science Projects to address those goals will be well-defined independently led activities developed before the beginning of SKA science.*

[2] *Ownership of infrastructure has not yet been determined.*

the planning and conduct of SKA operations and science. The members will be appointed on the basis of their scientific expertise and experience.

3.3 Scope of SKA Operations

SKA Operations is defined as the sum of all SKA activities that are centrally or jointly managed, and which are neither part of the SKA Construction Project, nor Planning Activities.[3] For this purpose, managed activities include those contracted out, provided in kind by agreement, or similar.

SKA Operations will thus include:

1. Science Operations
2. Engineering Operations
3. Management and Administration
4. Commissioning of Construction Project deliverables

SKA Operations includes delivery of quality-controlled calibrated data and provision of tools for project preparation and data analysis, but excludes science analysis, and publication of users' results.

Some of the SKA partners may elect to engage in additional SKA-related activities, such as further user services, that could be locally or regionally funded, while such services would remain outside the management or contract structure of the SKA Observatory and its core activities.

During the construction phases some individuals (e.g., the SKA Director-General) may hold dual roles within Operations and the Construction Project.

3.4 Host Country Operations

Operations in the Host Countries will be part of the SKA Observatory and managed by the GHQ. The managers of Host Country activity will report functionally to the SKA Director-General, within the context of the contractual relations or the overall management structure chosen for the SKA Observatory.

3.5 Other SKA Observatory Roles

There are additional roles that the SKA Observatory will have, in common with other observatories:

- Organise and conduct on-going improvements/upgrades
- Retain technical expertise
- Provide scientific leadership

These roles are not considered in detail in this document. Nevertheless, the operating model of the observatory implicitly enables them, since retaining the expertise of relevant individuals and access to the staff of related organisations will be essential to the day-to-day conduct of the observatory.

3.6 Success Metrics

Both scientific and operational metrics are needed to guide the management of an observatory. The ultimate goal is maximum scientific discovery and impact. However, operational success metrics are more easily linked to day-to-day operations and can provide earlier diagnostics of the likelihood of scientific success.

[3] *These terms are defined in the glossary.*

Scientific success metrics

The primary success metric for the SKA Observatory will be the significance of its role in making fundamental scientific discoveries and facilitating overall scientific progress, expressed as high impact, peer-reviewed scientific papers using SKA data. Additional success metrics such as the total number of users, etc., will also be developed and measured.

Operational success metrics

Operational success metrics will commonly be dependent on the individual telescope design and/or technology, and on the scientific strategies and success metrics. Sustainability, efficiency, telescope and data availability, and user support level are examples of success indicators related most to breadth and size of the user base, while operational success metrics measuring capability and performance may be particularly important to monitor the ability to achieve specific high-impact science results.

4 Science Projects

The SKA Observatory will be designed to accommodate a mix of large co-ordinated observations proposed by large teams and short PI-driven programmes.

4.1 Key Science Projects

A limited number of large observing projects designed to address the Key Science Programs will be allocated a substantial fraction of observing time [RD3]. These will be called Key Science Projects (KSPs). KSPs will fulfil several purposes:

- Allow a coordinated approach to ensure that key science objectives are addressed efficiently and effectively
- Facilitate the delivery of derived data products (catalogues etc.) as resources back to the wider scientific community
- Facilitate the sharing of knowledge and expertise among the SKA Members through extensive scientific and technical collaboration
- Provide a mechanism for ongoing oversight of observing programs that consume large observatory resources (principally observing time).

The initial KSPs will be observing programmes that satisfy one or more of the following criteria:

- Substantially address the key science objectives identified for the SKA
- Require large observing time allocations (commonly > 1000 hrs) over a period longer than one year but no more than five years
- Require substantial dedicated or customised observatory resources.

Key Science Project teams may propose for specific data processing resources and other support that may be available from the SKA Observatory, but they are also expected to arrange for significant additional resources themselves.

4.2 PI Projects

The SKA will also conduct a program of observations driven by proposals from individual researchers and teams, on the basis of published announcements of opportunity. The time will be allocated based on proposals submitted for evaluation under a process organised by the SKA Observatory. The lifetime of these proposals will normally be for a single proposal cycle (likely to be 6-12 months). In certain cases longer projects will be approved but subject to a process of on-going review.

4.3 Access Policy

The SKA Board will define the SKA Access Policy governing the right to propose for observations and to have access to archived data. The high-level principles adopted are [RD4] :

- That access should be based on scientific merit for scientists within Member states, evaluated via a single time assignment process
- That there should be a mechanism to ensure access is proportional to contribution level for each Member state
- That provision should be made to enable access for non-member states at a level to be determined
- That all data/data products are to be made globally available after a suitable proprietary period
- That the Director-General will formally allocate time.

4.4 Director-General's Time and Staff Access

A small percentage of observing time will be left unallocated for use at the discretion of the SKA Director-General. Staff will access the telescope through the same mechanisms as other scientists. There will be no specific allocation of telescope time reserved for staff. However, the access policy will make provision for staff employees of SKAO or operating partners to access the telescope irrespective of their association with an SKA member.

5 Science Operations

Science Operations comprises the broad range of activities needed for the scientific use of the SKA Telescopes. These include all stages of the observing cycle, from preparing and submitting a proposal, preparing for and taking observations, using data archives and working with the data or data products obtained. Science Operations and Engineering Operations will need to be in close contact in many circumstances and staff should be co-located where possible.

5.1 Proposal Handling and Time Assignment

Proposals will be accepted for a regular observing cycle (likely to be once or twice a year) and will be ranked according to scientific impact and assessed for feasibility with the requested telescope. In certain cases the resources made available by proposers for large projects will be a discriminant in obtaining observing time. Following merit review and time assignment[4] according to the access policy (section 4.3), projects will each be broken into one or more scheduling units capable of being individually observed. A prioritised list of the scheduling units will be formed for each telescope. To ensure efficient use of telescope time, the list may consist of more scheduling units than can normally be observed in the observing cycle. The proposers will be informed about the outcome. This process will be supervised and conducted by GHQ.

5.2 Telescope Scheduling and Observations

Observations will be carried out in scheduling units according to the prioritised list, taking into account target availability and environmental conditions. The sequence of scheduling units will accommodate the requirement, through a mechanism to be determined, to ensure access is proportional to contribution level for each Member state (§4.3). Maintenance and other local scheduling constraints, and any coordination needed with other observatories, will be the responsibility of local telescope staff. The local staff will also have limited discretion to vary the order of observations from that in the prioritised list to ensure efficient observing, and with approval of GHQ to carry a small number of scheduling blocks to the next observing cycle, provided that the overall prioritisation is maintained. Observations will be conducted by Observatory staff. Other than for time-critical and custom projects, project team members will not normally participate in the observing or receive the data in real time. This is motivated by the high efficiency enabled by flexible scheduling and by the complexity of the system.

5.3 Data Processing

Both image processing and time-domain processing will be supported. Image processing will deliver images of the sky in radio wavelengths. Image processing is an iterative process, and access to raw and intermediate data products is required throughout the process. However, raw data volumes from the SKA are expected to be too large to store permanently, and will have to be buffered. For many imaging observations, only the final image data will be stored. Some time-domain processing will also take place in near-real time. Detailed definition of data processing requirements and limitations for both imaging and time-domain processing will occur during the design phase of the SKA.

Data processing will take into account the current state of the telescope system (system model), as well as all of the known events that occurred during the observation (see section 6.2). The events will include RFI, weather events, bad data detected upstream, etc. Real-time processing will be carried out

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[4] *Actual observing time will normally be allocated, rather than guaranteed outcomes (such as sensitivity).*

only where warranted (e.g. events that require a decision, action or response). Otherwise the processing system will be designed to keep up with the average load.

5.4 Calibration and Data Projects

The SKA Observatory will calibrate SKA data and make science-ready data and ancillary products available to the users. The SKA Observatory will produce tools, procedures, pipelines and databases to collect and track calibration data and instrument performance so as to ensure the delivered data products achieve and maintain a pre-defined target calibration accuracy. Each observational mode of the SKA will be covered by a calibration plan, defined, maintained and evolved by SKA science operations. A customised calibration plan will be developed for Key Science Projects, and for other projects where an adequate case is made and resources are available.

5.5 Data Persistence and Science Archive

The SKA Observatory will provide an archive with a data management system to support data-intensive astronomy. Appropriate selections of the data collected by the SKA (visibilities, cubes, images, logs, monitor and control streams, proposals, schedules, etc.) will be stored for the lifetime of the observatory. The data products to be stored will be those identified during the design phase for Key Science and for the other capabilities defined in the baseline design. The final distributed data products of the Observatory, together with relevant metadata, will be stored in a science archive system that incorporates appropriate data delivery and interoperability interfaces, including Virtual Observatory interfaces. A backup, not necessarily accessible in real time, will be maintained. Additional archive capabilities such as data discovery tools or storage for derived products may be provided by partners, but will not be funded through SKA Operations.

5.6 User Support

The SKA Observatory will provide user support and tools to enable exploitation of SKA data. These will include tools and documentation for proposing observations, planning observations, accessing the data archive, and analysing data, for users of a varying level of capability and expertise. Tools, documentation and support will assume an understanding of the principles of radio astronomy and interferometry, but not an in-depth knowledge of the SKA design and performance. General-purpose analysis tools not uniquely required for SKA data will not normally be provided by the Observatory. The tools will be operable from anywhere, via the Internet. “Helpdesk” support for the tools will be provided. Training, in-person support, and detailed help for non-radio-astronomers to turn their scientific goals into observational programs are essential for the success of the observatory and may be provided in a regional model, not funded through SKA Operations.

6 Engineering Operations

Engineering operations comprises those activities necessary for the maintenance and upgrading of the telescopes (including on-line and data pipeline software, and the archives) and SKA infrastructure in the host countries. Engineering operations is conducted in the host countries, in reasonable proximity to the telescopes.

Engineering operations is a broad area with impact on a number of the telescope systems and design, including logistics and support systems. In the ConOps we focus on the guiding principles of engineering operations. The more structural aspects, such as the size and rotation schedule of engineering maintenance staff will need to be guided by the telescope design which includes consideration of system availability and cost, protection of the RFI environment, etc. It is reasonable to assume at this stage that the contingent of maintenance staff on site will be small.

There is a variety of cost trade-offs to be made during the design and operations phases of the SKA. The main principles are:

- maximize science return through system availability engineering in the design phase
- protection of the radio quietness of the sites
- reducing the human footprint of support staff at the sites
- maximum use of line replaceable units especially at the remote sites
- remote diagnostic and repair capabilities
- maintaining control of the current and historical configuration of the telescopes
- planning for upgrades to the systems over the lifetime of the telescopes.

6.1 Availability and Cost Implications

Availability is influenced by all of the operational support functions of the Observatory, including administration, documentation, procedures, safety, site access, etc. A particularly important component is maintenance of the telescopes, including their support infrastructure, computing, etc.

While the design lifetime of the Observatory is 50 years (section3), in practice the Telescopes will comprise a mix of components, some of which are likely to be replaced (or upgraded) on a regular basis, while others will not be upgraded over the lifetime of the Telescopes. Thus, consideration needs to be given to this in the design of the telescope support systems and provision of spares.

There are three major aspects to SKA Telescope availability:

- Definition of availability that is tailored to the SKA situation,
- Reliability, Availability and Maintenance (RAM) models to support the uptime requirements of the telescope system and inform operational costs,
- Cost models that fit within capital and operating cost budgets.

Neither the operations of any of the SKA1 Telescopes nor the cost of operations can be understood without an analysis of availability, nor can the design be completed. As used here, availability is the probability that a telescope or component thereof is available to be scheduled for astronomical observations at any given time. Measured ex-post-facto, it is the ratio of up-time to elapsed time at a component or telescope level.

The starting point for the RAM model is the precise definition of availability for each SKA1 telescope and the setting of an availability requirement. In principle, the definition should reflect the inherent robustness of the synthesis telescope system, its parallelism and capability to carry out science operations in a degraded state. This definition is then used to set the actual availability requirements. Although there is no unique method, a reasonable way forward is to define three system states:

‘available’, ‘degraded’ and ‘unavailable’. The requirements then specify the design goals for the fractions of time in each state.

Setting the overall system (telescope) requirements is the starting point for the parallel design processes of: 1) determining design lifetimes for each sub-system or component, 2) developing a maintenance plan, and 3) tracking the balance of capital and maintenance costs. Note that the ‘cost balance’ does not necessarily mean that a minimum lifetime cost is reached; it is likely to be constrained by limits on available operational and capital funds.

Availability defined at the system level must be allocated to sub-systems, each of which will carry out a similar analysis, eventually rolling back up to the system level for verification. The actual detailed process for doing this encompasses the RAM model noted above, the support for which will require the appropriate engineering tools.

Maintenance

There are SKA-specific factors beyond standard availability requirements that require particular attention and for which additional design effort and capital expenditure is justified. These are needed mainly to keep human occupancy on the sites to a minimum, as well as to enhance maintenance efficiency:

- Remote diagnostic and repair: In practice, this means that the monitor and control systems allow for a deep level of interrogation of sensor values and system state.
- Line-replaceable units: On-site repair will be particularly difficult and expensive at the remote sites. Systems should be designed to contain line replaceable units where feasible.
- Configuration Management System: Configuration management is a systems engineering process for managing the logistics of maintenance, tracking system documentation, and supplying real-time information to inform the system model. For this to work properly the system model must be tailored to SKA requirements.

6.2 System Model

The System Model is a framework for defining and tracking the state of the system as a function of time. The model enables a variety of ‘users’ to obtain information about the system relevant to their current needs. Its realisation may be distributed or confined to one location. The design and implementation of the model will be dependent on the projected needs of users, moderated by feasibility and cost. There are two time domain aspects that must be defined: the time resolution for allowed changes in state and access time for information by users of the model. Access procedures must also be clearly defined. The system state will be archived.

Information about the system state for a given time may be updated much later than real time. For example, final calibration information may not be available until weeks after the system time to which it applies.

Examples of user (both contributors and enquirers) groups are: maintainers, operators, schedulers, science data processors, system performance evaluators, and managers.

The model containing the state-of-the-system will be informed by data from many sources (e.g. schedule information (as observed), telescope manager monitor data, meta-data from observations, calibration data, RFI data, weather events, bad data detected upstream, etc.). It also includes information from the Configuration Management system (see section 6.1) regarding installed parts, fault conditions and changes in system documentation.

6.3 Protection of Radio Quiet Sites

The SKA Telescopes will be located within radio quiet zones provided by the Host Countries of South and Southern Africa and Australia. These zones are a globally unique resource. The sites, as radio astronomy preserves, must be treated as having indefinite lifetimes. A requirement of SKA Operations is to preserve the ability to place future telescopes on the sites, and in particular to maintain the radio quietness. Standards for each site will be agreed with the SKA Observatory. The host countries will have an obligation to protect to agreed standards the radio quiet zones for the SKA and future telescopes from outside transmissions and other telescopes on site. The SKA Observatory will have responsibility for control of self-interference from SKA telescopes. In addition, the SKA Observatory has a responsibility not to pollute the RFI environment for other telescopes on site. The SKA Observatory will need access to RFI monitoring facilities or data and will have a program in place to ensure compliance of its own equipment with the agreed standards. The observatory will engage in international spectrum management forums (e.g., IUCAF). In order to influence the design, the following will be required early in the design phase:

- RFI self-compliance standard
- RFI coordination, consultation and dispute resolution procedures.

6.4 Reducing Human Footprint on the Sites

For reasons of maintaining low self-generated RFI levels on the protected sites, coupled with considerations of travel cost, safety, and staff recruitment and retention, it is desirable to minimise the human footprint on the sites. While it will not be affordable to design and deploy full telescopes that require no maintenance at all, the guiding principle is to deploy only small teams of maintenance staff. This must be taken into account in the development of the RAM model.

6.5 Support for System Upgrades

As the full system capability will not be delivered on day one and technology advances will inevitably lead to incremental system upgrades, the telescopes should be designed to cater for this. For example, new software capabilities may be added on a regular basis and computing hardware may be refreshed to take advantage of improved performance and power consumption. The exact model of upgrades still needs to be determined in terms of small or large increments, but the SKA design should assume that substantial parts of the infrastructure will undergo cycles of minor and major maintenance as well as upgrading to follow the scientific and technical state-of-the-art. The length of these cycles will probably differ between components of the SKA telescopes.

7 Management and Administration

Management and administration will be located primarily at the Global Headquarters and in the host countries.

7.1 Global Headquarters

The SKA Global Headquarters (GHQ) will be the administrative centre for the construction and operations of the SKA. Headed by a Director-General, the GHQ will collect together activities of the SKA that are required to be co-located and which do not (necessarily) need to be at one or both of the host countries. The GHQ will be ultimately responsible for the scientific success of the SKA. The following functions will be carried out at the GHQ:

1. Overall management
2. long-term policy direction
3. financial oversight
4. relationship with funding organisations
5. legal and business affairs related to international agreements
6. PR, communications, policies on SKA branding
7. mandating and managing technical and user support standards
8. mandating and managing RFI protection standards
9. scientific direction and monitoring of the key performance indicators (science impact)
10. final proposal evaluation and time assignment
11. administrative support for the SKA Board.

An analysis of these functions will be needed to obtain an estimate of the staff required to carry out the above functions. Depending on the operating model, a small group of ancillary staff (e.g., human resources management) will also be needed.

The Global Headquarters could be co-located with a host country facility. If so, the functions described for those entities would also be carried out in the same location, but logically separated from the functions described above.

During construction, the Global Headquarters is expected to have additional functions not directly related to Operations, e.g., oversight of contracting and procurement.

7.2 Host Country Activities

The administrative and management functions in the host countries will be limited to those necessary to control SKA infrastructure and conduct SKA operations in the country. Functions will include:

1. Land access and management, for the SKA telescope site and other SKA-related sites in the host country,
2. Application of the host country legal, business, procurement, import/export, regulatory and fiscal/accounting frameworks to the SKA,
3. Long-term aspects of radio frequency protection as noted in section 6.3,
4. Establishment of arrangements with regional countries in Africa hosting SKA infrastructure,
5. Business activities (finance, contract management, legal, human resources, etc.) necessary to conduct SKA Operations in the host countries.

7.3 Outreach

Public relations and outreach are essential parts of any large scientific facility. It is likely that each of the contributing countries and institutions will have outreach programmes. These will typically be coordinated through the SKA members and funded directly by participating countries and organisations. These outreach activities will be coordinated (not controlled) by the Global Headquarters. The GHQ will, however, also have staff engaged in public relations activities. The SKA Observatory, through the GHQ, will have responsibility for control of the SKA brand.

8 From Construction to Operations

8.1 Beginning of SKA Operations

The SKA Operations capability will be established early during the construction of the SKA, in preparation for receiving site infrastructure, telescope hardware or software when delivered by the SKA Construction Project. It will become the responsibility of SKA Operations to commission, maintain, and eventually decommission (and possibly replace) the components.

However, where there is substantial technical risk in a subsystem (e.g., a new technology) then handover to Operations will occur only once the Construction Project has retired most of the technical risk. For example, this will generally require a complete working subset of the relevant telescope to be available to the Construction Project for verification activities. Once a subset of the telescope is operational, further components (e.g. receptors, correlator components) could be delivered individually to Operations following integration and testing.

A dedicated commissioning and performance evaluation team will exist to monitor performance and provide feedback to the Construction Project.

8.2 Acceptance, Integration, Commissioning, Operations

Distinct groups, responsible for acceptance, integration, commissioning and routine operations, respectively, will be assembled for construction and the transition to steady-state operations. Acceptance and Integration will be the responsibility of the SKA Construction Project. Commissioning of the telescope system and Routine Operations will be the responsibility of SKA Operations within the host countries.

Acceptance

Acceptance procedures will be followed for all deliverables: performance verification and quality evaluation according to terms of contract will be the responsibility of the Construction Project. Accepted deliverables will be handed over to the Integration Group.

Integration

Deliverables will be subjected to further evaluation by the Integration Group, optionally in specific test facilities, as required to reduce technical risk that could not be ascribed to the original supplier. The goal is to further reduce risk and to ensure that integration of deliverables into the system occurs smoothly. The Integration Group will be responsible for set-to-work and system integration of evaluated deliverables and will hand them over to the Commissioning Group.

Commissioning

The primary responsibility of the Commissioning Group is to ensure that the entire system is on track to meet performance criteria, including science verification. The Commissioning Group will plan and carry out continuous performance evaluation of the entire system as it grows. The Commissioning Group will also carry out deep in-system performance evaluation of components and software handed over from the Integration Group, whenever possible in conjunction with science operations. Changes to the design of components, retrofits and/or future production changes may result from the evaluation by the Commissioning Group. Any changes would be proposed to the change control board for the Construction Project. The Commissioning Group for SKA1 will be retained until the telescopes reach a steady state and/or when the transition to SKA2 occurs.

Routine Operations

The Operations Group will be responsible for regular science operations, maintenance, data processing and related activities. During the early stages of system growth, this group will be responsible for the planning of Early Science in conjunction with the Commissioning Group. The dual goals of Early Science are to carry out scientifically useful observations and to use these observations as tools for evaluating system performance. Some staff trained in the Integration and Commissioning Groups will be retained in the Routine Operations Group.

8.3 Incorporation of Precursors

Three precursor telescopes are present or under construction on the SKA sites in the host countries: MeerKAT in South Africa and The Australian SKA Pathfinder (ASKAP) and Murchison Widefield Array (MWA) in Australia. Portions of MeerKAT and ASKAP and their infrastructure will be included in the SKA, maximising their use based on a cost benefit analysis. Disruption to the precursor science programmes will be minimised while expediting the build-out of SKA Phase 1 at both sites. The planned precursor programs are expected to take approximately 5 years assuming a high level of availability.

9 Operational Modes

9.1 Normal Observing

Normal observing will consume most observing time for both Key Science Projects and PI Projects (section 4). Projects observed in this mode will be characterised by the lack of special requirements for equipment, support, or scheduling. PIs and project team members will not normally participate in the observing or receive the data in real time. The observatory will have the flexibility to schedule these projects dynamically, and to break them up into schedulable blocks that optimise the use of telescope observing time (section 5.2).

9.2 Observations on a Fixed Schedule

Some time-dependent phenomena will require observations made at a fixed time. The GHQ will schedule such observations.

9.3 Time Critical Over-rides

There will be a mechanism for requesting observing time outside the normal processes. This may occur for observations of unpredicted phenomena or in cases of high current scientific interest. The process will be conducted by GHQ. Host country staff will be consulted to ensure neither staff nor equipment is harmed and to balance against approved observations of time-critical phenomena and maintenance schedules. There will be provision for automatic overrides on a timescale to be determined on the basis of a balance between science goals and telescope capability and cost.

The Director-General or his/her delegate shall have the power to override allocation of time to other projects.

9.4 Custom Experiments

The design of the SKA will allow the conduct of a limited number of custom experiments that are not fully supported by the Observatory or that require a higher level of support. For example, where the SKA maintains appropriately documented standard interfaces, custom hardware may be used for data acquisition, or user-provided software may replace the standard data pipeline. Data may be provided in real time.

Such experiments will be subject to the normal review process. The review process will take into account any risk or inefficiency (e.g., wasted or unscheduled telescope time) that may be inherent in scheduling the projects, and to ensure that equipment (if any) meets established standards. We note that supporting custom experiments can be very expensive: the review process will also consider whether observatory resources are available. Users will be responsible for providing data suitable for archiving. The requirement to archive SKA data products in the SKA Archive will be waived only in exceptional circumstances.

9.5 Commensal Observing

Commensal observing is defined as observing where two or more projects share the same dataset. Because Observatory resources will still be required to support commensal observing, the normal processes of review will apply to each project. Commensal projects shall not be allowed to exploit data in ways allocated to other projects sharing the same data. An extension of this use case is a project that requests further processing of archival data, within its proprietary period, for other goals than the primary program; if such projects can be facilitated, they will likewise go through the normal processes of review. The question of rights to serendipitously discovered phenomena is subject to future discussions on the Access Policy.

9.6 Collaborative and Coordinated Observing (e.g., VLBI)

The SKA may sometimes be used in collaboration with other telescopes not operated by the SKA Organisation: for example, observations coordinated in time with observations at other facilities. Such observations will be treated as special cases of one of the above types of observation (with a proposal to the SKA Observatory required), except that the Observatory will participate in dialog directly with other observatories for the purpose of scheduling. Very Long Baseline Interferometry (VLBI) with non-SKA Telescopes (e.g. space observatories) will be supported.

9.7 Maintenance

For a fraction of time the telescopes will be unavailable due to planned or unplanned maintenance (section 6.1).

9.8 Subarrays

The scientific need for subarrays will be determined as a result of an analysis of use cases. The requirement for subarrays for operational purposes (e.g., to optimise telescope use by allowing commissioning, calibration, maintenance, or routine observing to proceed simultaneously) will be evaluated during the design phase, with the decision to be made on the basis of a cost-benefit analysis.

10 Cost of Operations

The design of the operational model (including operational cost) will form part of the design of the SKA Telescopes, and any constraints on operational funding will be a constraint on the Construction Project. This will help to ensure that the telescopes constructed can be operated for the likely available funding. Specifically, it will constrain the trade-off between telescope performance/scope and operating expenses, by constraining the former. For the SKA, the major operational cost areas are electricity and labour, in particular on-site maintenance labour. The costs must be minimized during the design phase. The approach to maintenance labour cost minimisation was described in section 6.1.

Consumption of Electrical Power

The cost of electrical power may be expected to rise significantly in the medium term. Because of the remoteness of the sites from sources of electricity, there will be a strong emphasis on explicitly minimising its use in the design of on-site facilities and telescope components. Consideration of the use of capital funds to enable lower power consumption will be warranted in these designs, so as to lower overall capital and operating expenses. However, the science data processor will be the major consumer of power. Cost factors for the science data processor, including location (which will influence cooling cost), must also be considered during the design phase.

11 Glossary

Planning Activities: The activities leading to the definition of the capital project plan (or a major phase of the plan), and the operations plan. Planning includes project definition, system engineering and design. It includes the Preparatory and Pre-Construction phases of the project schedule, and any of the planning activities that are required for SKA2.

Construction Project: Everything defined in the capital project plan. Anything not explicitly in the capital project plan is not part of Construction.

Operations: The sum of all SKA activities that are centrally managed, and which are neither part of the SKA Construction Project, nor Planning Activities. For this purpose, managed activities include those contracted out, provided in kind by agreement, or similar.

SKA Observatory: The SKA Observatory will consist of SKA Telescopes, local activities necessary for their operation, data processing and archive facilities and a Global Headquarters.

SKA Telescope: A single scientific instrument of the SKA that can operate as a coherent system independently of other telescopes, but which may share resources, including software, with other telescopes. Each telescope will include the necessary hardware (including data storage) and software to produce quality-controlled data products capable of being distributed to users.

User: A person or organisation that proposes a project for the SKA, plans an accepted observing project, assists with observing (except as a GHQ or host country staff member), or receives data from the SKA archive for a scientific purpose.