# SKA1 ASSEMBLY, INTEGRATION AND VERIFICATION (AIV) TECHNICAL DESCRIPTION

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## ORGANISATION DETAILS

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LIST OF ABBREVIATIONS

AIV........................................Assembly, Integration and Verification
ASKAP....................................Australian SKA Pathfinder
ASTRON.................................Netherlands Institute for Radio Astronomy
CDR.................................Critical Design Review
CSIRO.................................Commonwealth Scientific and Industrial Research Organisation
CSP.......................................Central Signal Processor
DSP.......................................Digital Signal Processing
GFRP.................................Glass Fiber Reinforced Polymer
HW.....................................Hardware
ILUA.................................Indigenous Land Use Agreement
I&T.................................Integration & Test
KAPB.................................Karoo Array Processor Building
MeerKAT...............................64-dish Karoo Array Telescope
MRO.................................Murchison Radio-astronomy Observatory
MSF.................................MRO Support Facility
MWA.................................Murchison Widefield Array
NRF.................................National Research Foundation (in South Africa)
PAF.................................Phased Array Feed
PCB ....................... Printed Circuit Board
RFI ...................... Radio Frequency Interference
RfP ........................ Request for Proposal
SDP ........................ Science Data Processor
SKA ........................ Square Kilometre Array
SKA SA ........................ SKA South Africa
SW .......................... Software
TM .......................... Telescope Manager
VE ............................ Verification Event
1 Introduction

A Request for Proposals was issued by the SKA Office on 12 March 2013 for work packages to execute the pre-construction phase of the SKA project. One of the work packages, for which a proposal was requested, was for Assembly, Integration and Verification (AIV). This document is a technical proposal in response to the AIV RfP.

1.1 Purpose and Scope of this Document

The purpose of this document is to describe the technical work that the AIV consortium will undertake during the pre-construction phase of the SKA. This technical work will consist of the following:

a) Defining constraints imposed by the existing infrastructure and precursors on the two host sites. The method of how the AIV consortium is proposing to define these constraints is described in Section 3.

b) Defining a Roll-Out Plan for the three SKA1 telescopes (SKA1_LOW, SKA1_MID and SKA1_SURVEY). The method of how the AIV consortium is proposing to define Roll-Out Plans is described in Section 4.

c) Defining a Detailed Integration and Verification Plan for the three SKA1 telescopes. The method of how the AIV consortium is proposing to define the Detailed Integration and Verification Plan is described in Section 5.

d) Clarifying roles and responsibilities for all contributors to the SKA1 AIV activities. The method of how the AIV consortium is proposing to define roles and responsibilities is described in Section 6.

The examples of roll-out plans and integration and verification plans shown in this document are for illustrative purposes only, to clarify the work that the AIV consortium will conduct during the pre-construction phase.

The RfP issued by the SKA Office (see [1], Section 8.1) requested that the Technical Description document should contain the following:

- A functional description of the Element
- Key component characteristics
- A performance analysis against the requirements
- Key Element Level requirements

However, since the AIV Element does not construct any telescope components, this information does not apply. The system engineering process followed by the AIV Element is described in [2].
2 References

2.1 Applicable Documents

The following documents are applicable to the extent specified herein. In the event of conflict between the contents of the applicable documents and this document, this document shall take precedence. Nothing in this document supersedes applicable laws and regulations.

None.

2.2 Reference Documents

The following documents are referenced in this document and are merely listed for convenience.

3 Site Constraints

One of the deliverables of the AIV work package is to identify site constraints, and to communicate these, via the SKA Office, to other SKA Elements.

These constraints include (but are not limited to):

- Constraints derived from hosting agreements
  - For example, it is believed that the hosting agreement will determine at what time a precursor may be integrated into the corresponding SKA1 instrument.
  - The hosting agreement might also put constraints on SKA1 construction, so that precursor operations are not unduly hindered (e.g. due to construction-related RFI).
- Constraints imposed on SKA elements by existing infrastructure
  - Specifically infrastructure that will not change as part of SKA1 construction, and that will be used by SKA1 Elements.
- Constraints imposed by interfaces with precursors
  - These interfaces need to be carefully defined, in order to facilitate integration with other SKA1 Elements.
- Constraints imposed by local regulations
  - These include working within radio quiet zones, guidelines on how to access the sites, etc.

3.1 Australian Site Constraints

Below are a few examples of constraints on the Australian site, which need to be described in more detail as part of the AIV work package:

Constraints arising from local regulations, for example:

- Working within the MRO Radio Quiet Zone, and installation of equipment that is a potential source of RFI.
- General rules and guidelines for access to Boolardy Station and the MRO. This will include safety inductions, accommodation arrangements and compliance with the Indigenous Land Use Agreement (ILUA).
- Suitable visas for international visitors working on SKA in Australia.

Constraints arising from existing science programs, for example:

- Working around scheduled observing periods for ASKAP, the MWA and other MRO-based telescopes.

Constraints arising from existing facilities and infrastructure, for example:

- Coordination of work to be staged at the MRO Support Facility (MSF) located in Geraldton, and work to be supported by the Geraldton team.
- Access to the MRO network equipment and the MRO-to-Geraldton fibre link.

Constraints arising from the requirements to integrate with precursors:

- Coordinating access to the ASKAP system or subsystems for the purpose of design validation, acceptance testing, and ASKAP integration. This may include:
  - The ASKAP dishes and PAF receiver systems,
  - Fibre or power cabling,
  - Back-end DSP electronics in the control building,
  - Timing, control and monitoring systems in the control building,
  - The power station.
• Physical and functional limitations of the ASKAP system and subsystems, as well as the MRO infrastructure.

Constraints relating to organisational aspects, for example:
• Negotiated agreements regarding the long-term design, maintenance and operation of the precursors as they are integrated into SKA1.

3.2 South African Site Constraints

Below are a few examples of constraints on the South African site, which need to be described in more detail as part of the AIV work package:

Constraints arising from local regulations, for example:
• Protection of the Karoo Array Reserve radio quiet zone.
• Regulations pertaining to site operations, such as safety.

Constraints arising from MeerKAT science programs, for example:
• Scheduling of SKA1 construction activities to reduce the impact on MeerKAT science (e.g. day/night scheduling).

Constraints arising from existing facilities, for example:
• Manufacturing and integration facilities, such as the dish shed.
• Support facilities.
• Accommodation.
• Data network access.

Constraints arising from existing infrastructure on the South African site, for example:
• Power supply limitations and cooling limitations for equipment installed in the Karoo Array Processor Building (KAPB).
• Power supply limitations for Dishes.
• Space available inside the KAPB for installing processing equipment.

Constraints arising from the requirement to integrate the MeerKAT Precursor into SKA1_MID, for example:
• MeerKAT frequency bands.
• Control & Monitoring interface requirements for the MeerKAT receptors.
• Data products from the MeerKAT receptors.
• Time and frequency reference interfaces to the MeerKAT receptors.

Constraints relating to organisational aspects, for example:
• Negotiated agreements regarding the long-term maintenance and operation of the MeerKAT system as it is integrated into SKA1.
4 Roll-Out Plan

4.1 Overview

The AIV consortium is responsible for establishing a high-level roll-out plan for each instrument during the pre-construction phase, i.e. for:

- SKA1_MID with precursor integration,
- SKA1_SURVEY with precursor integration,
- SKA1_LOW.

This roll-out plan needs to consider:

- **Sequencing** of implemented functionality, based on a prioritisation of requirements. The sequencing will be based on:
  - Functionality required for integration and verification. This prioritisation will be derived by the AIV consortium.
  - Prioritised early-science functionality. This prioritisation will be driven by the SKA Office.

- **Scale**: How many dishes are deployed, over what timescale and at which locations.

The integration of the precursors into the SKA1 instruments will require careful planning, and needs to incorporate the constraints, identified in Section 3.

Figure 1 shows an example of a roll-out plan summary (from the MeerKAT project). The diagram shows how the AIV activities are coordinated over time across the different levels of the system hierarchy.
The roll-out plan has three major components:

1. **Dish roll-out** (for SKA1_MID and SKA1_SURVEY) or **Station roll-out** (for SKA1_LOW):
   The location sequence (i.e. sequence of the location of installed dishes), and the rate at which dishes are rolled out, will be determined by the AIV consortium, and requires careful consideration to ensure that the roll-out plan best serves the AIV activities and early science.

2. **Array integration phases:**
   The roll-out of the three telescope arrays will occur in stages, also called “Array Releases”. The set of functionality required at each of these releases must be agreed, together with the number of dishes required in each Array Release. These requirements will influence the time-priority of requirements for the array processing elements.

3. **Precursor integration:**
   It needs to be established what the best timing is for integrating the precursors into the SKA1 arrays. Important considerations for this timing include the maturity of the SKA1 arrays and minimising disruption to the precursor science programmes.

The following sections provide more detail regarding the roll-out components and phases for each of the SKA1 instruments.

### 4.2 Roll-Out Plan for SKA1_MID

Figure 2 shows a high-level roll-out plan for SKA1_MID. It highlights the following:

- **At System Level:**
  - SKA1_MID Dish Qualification is a process that happens right at the beginning, and that is executed only once.
  - As the SKA1_MID Array ramps up, there are various Array Releases, consisting of a pre-determined number of dishes, and which are used to execute pre-determined tasks in order to perform system acceptance testing.

- **At Precursor Level:**
  - The MeerKAT Array is expected to be doing science before the SKA1_MID Dishes are qualified.
  - At some point in time, MeerKAT Receptors are integrated into the SKA1_MID Array.
  - It may be useful to integrate some SKA1_MID dishes into the MeerKAT array to facilitate SKA1_MID dish verification and to improve the science capability of MeerKAT (e.g. longer baselines).
  - The SKA1_MID Array will continue to ramp up, even after all MeerKAT Receptors have been integrated into the SKA1_MID Array.

- **At SKA1 Element Level:**
  - SKA1 Infrastructure and “Signal and Data Transport” development begins before the SKA1_MID Dishes are qualified, and continues for quite some time thereafter, even while the SKA1_MID Array is ramping up.
  - A minimum set of functionality of SKA1 Elements (TM, CSP and SDP) needs to be integrated into the Karoo Array Processor Building (KAPB), before the qualification of the SKA1_MID Dishes can proceed.
  - Further functionality of these SKA1 Elements is rolled out during the SKA1_MID Array ramp up phase, and verified at corresponding Array Releases.
4.2.1 SKA1_MID Dish Roll-Out

4.2.1.1 Roll-Out Sequence of Dishes

The roll-out sequence of SKA1_MID Dishes is determined during the pre-construction phase, and needs to consider:

- Practical considerations of the Dish construction process,
- Infrastructure readiness,
- Science capability,
- Precursor integration.

4.2.1.2 Dish Qualification

Dish Qualification is performed on the first (or first few) Dishes, to verify that the integrated Dish design meets all the Dish requirements. The Dish Qualification tests and procedures will be planned and executed by the Dishes consortium during the pre-construction phase, including the supply of specialised test equipment for the qualification procedure. The Dish Qualification ends in a Dish CDR.

4.2.1.3 Dish Acceptance Testing

Acceptance testing is performed on each Dish delivered from the production line to ensure that it meets all its requirements. Because the design is already qualified, the acceptance testing is typically a subset of the qualification tests, and is there to ensure that the production process is still producing compliant products.

The contracted dish manufacturer is responsible for performing the necessary factory acceptance tests, shipping the components to site, integrating the Dish on site and performing a site acceptance
test of the integrated Dish. The AIV team will perform an oversight role in the integration and site acceptance testing of the Dish, and will sign off the certificate of conformance.

After acceptance testing, the Dish may be tied into the array for array verification and array commissioning work.

Additional Dish commissioning work will also continue on individual dishes after acceptance, in order to fully characterise and calibrate the Dish for a range of operating conditions. This work will be performed by the commissioning team. Commissioning will also refine calibration models to maximise the achievable performance of the Dish under operating conditions.

4.2.2 SKA1_MID Array Roll-Out

System acceptance testing will be done in phases, called “Array Releases”. Each Array Release corresponds to a new set of functionality/maturity from SKA1 Elements, as indicated below.

The SKA1_MID array elements (TM, CSP, SDP) will perform lab qualification testing, after which they will deploy their equipment on site, followed by an on-site acceptance test. From here, the AIV team will integrate these elements into an array system and perform acceptance testing on the integrated array release. System acceptance testing of an Array Release is followed by an acceptance review. If accepted, the Array Release is handed over to the commissioning team for commissioning activities, followed by full operation.

The following subsections describe the array releases for the MeerKAT system, to provide examples of what the array releases for SKA1_MID could look like. The AIV consortium will define the array releases for SKA1_MID during the pre-construction phase.

4.2.2.1 Array Release #1

Number of Dishes: starting with at least 4.

Purpose:
- Verify key interferometric performance requirements of the system, e.g. phase and amplitude closure performance.
- Verify core functions in preparation for early science functionality.

The following observing modes will be required:
- **Continuum visibilities**: The continuum visibilities data will be used to test the basic imaging functionality and key interferometric performance specifications.
- **Beam forming**: The beam forming functionality and performance will be tested. Beam forming is the core function for many of the higher level science functionalities (pulsar timing, transient search, etc.).

4.2.2.2 Array Release #2

Number of Dishes: 32

Purpose: The purpose of the second array release is to verify all capabilities required to support early science in high priority areas. Early science requires operational software that will support regular, scheduled scientific observations.
The following observing modes will be deployed and tested:

- **Spectral line imaging:** Spectral line imaging is regarded as a high priority science function for SKA1_MID. A spectral line imaging capability on a 32-element array will enable a large amount of functional and performance testing, followed by shared-risk early-science observations. Experience with this functionality on MeerKAT will facilitate the establishment of this function on the SKA1_MID array. The location of a few of the first antennas that are deployed should be chosen to increase the MeerKAT baselines – this will improve the early science capability and enable array performance testing on long baselines.

- **Pulsar timing:** Pulsar timing is regarded as a high priority science for SKA1_MID and should be made available by the time of the second array release. This will enable additional functional and performance testing of the array, followed by shared-risk early-science observations. It is foreseen that the majority of the first 32 antennas will be deployed in the core of the array to facilitate early pulsar timing observations. The back-end functionality will have been tested and used on the MeerKAT array and should be simple to transfer to SKA1_MID.

- **Transient search:** If possible, functionality to perform transient searching concurrently to the other two modes should be implemented at this stage to increase the utilisation efficiency of the system.

### 4.2.2.3 Array Release #3 and higher

**Number of Dishes: 64+**

Purpose: Subsequent array releases will ensure that the full functionality of the system is implemented, tested and released for science observations. The sequencing of the roll-out of functionality will be performed in line with science priorities.

### 4.2.3 SKA1_MID – MeerKAT Precursor Integration

Figure 3 highlights the following processes regarding the integration of MeerKAT Receptors into the SKA1_MID Array:

- There will probably be some form of pre-integration process to modify/prepare the MeerKAT dishes to comply with the SKA1_MID dish requirements, which needs to be described by the AIV consortium. This might, for example, include the swapping-out of receivers.

- The MeerKAT Receptors need to be subjected to the SKA1_MID single-dish verification process, before being admitted to the SKA1_MID Array. Since the MeerKAT Receptors have already been acceptance tested and commissioned by SKA SA, the level of SKA1_MID acceptance testing is seen to be minimal, and depends mainly on the content of the pre-integration process.

![Figure 3: MeerKAT Receptor Integration into SKA1_MID Array.](image)
4.3 Roll-Out Plan for SKA1_SURVEY

Figure 4 shows a schematic overview of the key phases of the SKA1_SURVEY roll-out, namely:

- Dish roll-out
- Array roll-out
- ASKAP precursor integration

![SKA1 Survey Roll Out](image)

4.3.1 SKA1_SURVEY Dish Roll-Out

This phase will comprise two major activities:

The first major activity will be providing access to existing infrastructure and supporting the construction of new infrastructure. That is, regulating site access and supporting logistics for site activities. Providing access to the MRO and existing infrastructure will require site access agreements, site inductions and propagation of knowledge around the local rules and regulations. Support for the construction of new infrastructure will include the development of high-level interfaces with low changeability. AIV will provide input into the development of proposed infrastructure designs through interface documentation and consultation with all stakeholders. This is likely to include site surveys for antenna configuration, installation of underground cabling for fibre and power, supporting the creation of roads, development of repeater huts, control building and power systems.

The second major activity will be supporting the prototyping and demonstration of new SKA1 systems at the MRO site. This may include validation or development testing of first-of-type receiver, dish and infrastructure systems. The work may involve the creation (or support for the creation) of particular test facilities. It may also involve coordination of access to some ASKAP facilities including
power systems, the control building, weather station, lightning detection and RFI monitoring systems.

4.3.2 SKA1_SURVEY Array Roll-Out

The SKA1_SURVEY Array Roll-Out will overlap with the SKA1_SURVEY Dish Roll-Out. The work will support the assembly, installation and verification of the receiver electronics and other (non-infrastructure) sub-systems into the SKA1 system.

This work will include deployment of Receiver Electronics, Back-End pre-processing and Network Communication Systems, Timing, and Control and Monitoring Systems. It will include site acceptance testing of production items. It will also include higher-level integration and demonstration/validation of higher-level end-to-end SKA1 functionality.

Retro-fitting and regression testing of non-compliant systems will be supported as required.

Verification of physical and functional interfaces with the ASKAP antennas will start during this phase. Initially this may include the use of a small number of ASKAP antennas (probably 2 or 3) that have been taken off-line. Verification should include a demonstration of scalability in preparation for full ASKAP integration.

Agreements regarding the ongoing access to MRO and ASKAP facilities may need to be revisited and re-negotiated at this stage, prior to the completion of SKA1-ASKAP integration.

4.3.3 SKA1_SURVEY – ASKAP Precursor Integration

SKA1_SURVEY – ASKAP Precursor Integration will involve the complete integration of all 36 ASKAP Antennas, plus required ASKAP back-end computing and communications equipment, into SKA1.

There will be some overlap with SKA1_SURVEY Array Roll-Out. However, the SKA1 design should support scalability, allowing precursor integration to be performed over a relatively short period.

The completion of the full system integration will allow the completion of SKA1_SURVEY Engineering Commissioning and the commencement of Science Commissioning.
4.4 Roll-Out Plan for SKA1_LOW

SKA1_LOW consists of 911 stations (866 in the core and 15 stations in each of the three spiral arms), with each station consisting of 289 antenna elements. Each station is 35 meter in diameter. In the SKA1_LOW roll-out plan the breakdown of the roll-out phase into a number of discrete activity phases will be provided. It will thus provide an overview of the activities and resources (equipment and personnel) required during the various phases, which will result in a fully integrated and tested SKA1_LOW.

4.4.1 SKA1_LOW Station Roll-Out

The roll-out of each of the SKA1_LOW stations consists of the following phases:

- Site survey
- Ordering of components
- Site preparations
- Pre-test and integration in an I&T facility
- Installation of the hardware \( \rightarrow \) cabinets, antennas, etc., on the site
- Installation of network infrastructure
- Execution of the engineering test plan
- Validation
- Site acceptance

A number of plans, specifications and procedures will be written in order to execute the above-mentioned activities as planned. The written procedures might be improved and updated in view of the full roll-out.

4.4.1.1 Site survey

Each of the 911 sites in SKA1_LOW needs to be chosen depending on site conditions. Especially the sites in the three spiral arms need special attention.

4.4.1.2 Ordering of components

Ordering of components, the production of PCBs, antennae parts, etc, can be divided into a group will be subject to a supplier selection (tender) process, and a group consisting of the remaining components and services. A checklist will be maintained throughout the production, integration and test phases to trace all changes. The parts will be manufactured and tested according to specification. The PCBs will be delivered to an I&T facility, where they will be assembled into crates and racks. After they have been tested, they will be shipped to the station site.

4.4.1.3 Site preparation

Before a station can be built, a number of activities need to be performed, for example:
- The soil of the sites has to be leveled to a certain flatness.
- Building of a temporary road from metal or GFRP plates from the public road to the station.
- Cabinet structure has to be placed.
- Power connections have to be installed.
- Etc
4.4.1.4 Pre-test and integration in an I&T facility

Before shipping to the station location, sub-racks will be integrated and tested:
- Preparation of integration and test documentation.
- Incoming inspection of units and boards
- Individual and integrated rack assembly and test (rack level)
  ⇒ HW/SW integration and tests
  ⇒ Overall rack integrated functional tests with simulated antenna inputs

4.4.1.5 Installation of the hardware on the sites

This involves the complete installation of all the hardware and equipment of the sites.

4.4.1.6 Installation infrastructure

This includes installation of signal infrastructure as well as power infrastructure.

4.4.1.7 Execution of the engineering test plan

The tests will be detailed in the engineering test plan. Part of the tests will be performed before first light, whereas other tests will be performed off-line in the I&T facilities. The remaining tests are:
- Station level tests
- Station correlation tests
- Weather condition tests
- Station calibration tests
- RFI mitigation tests
- Clock accuracy tests

4.4.1.8 Station validation

Definition of validation: “Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled”.

Validation of a station will be based on the successful execution of the engineering test plan.

4.4.2 SKA1_LOW Array Rollout

System acceptance testing will be done in phases, called “Array Releases”. Each Array Release corresponds to a new set of functionality/maturity from SKA1 Elements, as indicated below.

System acceptance testing of an Array Release is followed by an acceptance review. If accepted, the Array Release is handed over to the commissioning team for commissioning activities, followed by full operation.

The AIV consortium will define the array releases for SKA1_LOW during the pre-construction phase.
The following array releases are anticipated:
- SKA1_LOW array release 1: 4 stations
- SKA1_LOW array release 2: 20 stations
- SKA1_LOW array release 3: Core
- SKA1_LOW array release 4: Core plus the 3 spiral arms

Each array release will have an Astronomical Test Plan.
5 Detailed Integration and Verification Plan

Another important deliverable for the AIV consortium during the pre-construction phase is to define a Detailed Integration and Verification Plan. This plan is based on the roll-out plan, but provides sufficient detail that can be used during the construction phase to perform project management of the AIV. Another important purpose of this plan is to establish traceability between the AIV activities and the originating system and element requirements (see Figure 5).

The Detailed Integration and Verification Plan:

- Identifies all required integration activities.
- Identifies all Verification Events (VEs) that are required at the different stages of integration to ensure thorough verification.
- Identifies test procedures that are required to perform the verification.
- Identifies resources required for the verification, including:
  - Human resources
  - Specialised test equipment
- Establishes a timeline, in the form of a project plan, for all these activities.

The traceability between elements of the detailed integration plan is shown in Figure 5.

Figure 5: Relationships between elements of the detailed integration plan.

Figure 6 and Figure 7 show examples of how such detailed integration planning frameworks can be represented. Frameworks similar to these will be used to do the detailed integration planning for each of the three instruments.

Figure 6 shows how components are integrated into the system on a phased timeline. The activities are split between lab integration and site integration activities. For each major activity, a list of Verification Events (VE…) is provided. Each of these Verification Events is associated with a test procedure, which is traceable to the originating verification requirements and system requirements. Such a detailed plan ensures that all requirements of the system are verified at an appropriate time in the integration sequence.
Figure 6: Example of identification and sequencing of Verification Events (from the KAT-7 project).

Figure 7 shows an alternative representation of such a planning framework (snapshot of KAT-7 integration plan taken in August 2009). The major component deliverables are shown as blocks on a calendar timeline. The colour of these blocks indicates deliverable status (green = done; red = late; pink = planned). Integration activities are shown as small circles. At each integration or verification activity, the Verification Events (which are traceable to requirements) are listed. Interdependencies between these activities are shown with arrows.

Figure 7: Example of graphical view of detailed integration plan (from the KAT-7 project).
6 Clarification of AIV Roles & Responsibilities

For each instrument (SKA1_MID, SKA1_SURVEY and SKA1_LOW) the following teams or role players can be identified:

- Element Team
- AIV Consortium Team
- Engineering Support Team (part of the operational team)
- Commissioning Team
- Operators
- Maintenance Team

Each of these teams may be responsible for:

- Coordinating
- Executing
- Supporting
- Participating in
- Observing

And these responsibilities may be mapped to each of the following processes (not all of which are part of Integration & Verification):

- Lab integration
- Qualification testing
- Qualification review
- On-site installation
- On-site acceptance testing
- Site integration
- Acceptance testing
- Acceptance review
- Commissioning
- Operation
- Maintenance

These activities are staggered over time and occur in different locations. An example of this is shown in Figure 8, showing the sequence of activities leading up to Receptor qualification for the MeerKAT receptors. These sequence diagrams will be defined for the AIV activities for the different elements and for the telescope systems.

Figure 8: Activities leading up to qualification of receptors
As part of the AIV work package, these roles and responsibilities will be clarified for the various AIV activities. An example of such clarification of roles and responsibilities is shown in Figure 9.

<table>
<thead>
<tr>
<th>Subsystems</th>
<th>Subsystem team</th>
<th>Engineering Support team</th>
<th>SE team</th>
<th>Commissioning team</th>
<th>Operators</th>
<th>Maintenance team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab integration</td>
<td>execute</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Qualification testing</td>
<td>execute</td>
<td>-</td>
<td>observe</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Qualification review (QTR)</td>
<td>execute</td>
<td>-</td>
<td>participate</td>
<td>participate</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Install on site</td>
<td>execute</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Site acceptance test</td>
<td>execute</td>
<td>-</td>
<td>observe</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

| System                     | support        | execute                  | coordinate & execute | - | - | - |
| Lab integration & fixing problems | support        | execute                  | coordinate & execute | - | - | - |
| Lab testing                | support        | support                  | execute              | - | - | - |
| Site integration & fixing problems | support        | execute                  | coordinate & execute | - | - | support|
| Acceptance testing         | -              | support                  | execute              | support | - | support|
| Acceptance Review          | -              | -                        | execute              | participate | - | - |
| Commissioning              | -              | support                  | execute              | support | support | - |
| Operation                  | -              | -                        | execute              | support | support | - |
| Maintenance                | -              | support                  | -                   | -       | execute | support |

**Figure 9: Example of Roles & Responsibility matrix (from the MeerKAT project).**
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