SKA System Concept Design Review

Panel Report

19 March 2010

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Summary

The key findings and recommendations of the Review Panel are summarized below:

1. The Panel was impressed by the preparations for the review and the degree and professionalism of the SKA systems engineering. The Panel appreciates the rapid response to questions submitted shortly before the review. The documentation provided was of a high standard and covered all relevant aspects. This gave a lot of confidence in the SPDO led effort.

2. The SKA team seemed to have recognized about 95% of the problems (but recognizing a problem does not mean it is solved or that it is solvable). The Panel could only identify two possible gaps: security of hardware at remote sites, and export controls.

3. SKA in its present setup tries to push technology limits on pretty much <u>all</u> fronts. Some parameters are pushed orders of magnitude beyond state-of-the-art. Even things that traditionally have been minor problems are now an issue (e.g., power, computing, signal transport & processing, …). Given current time and cost constraints the Panel felt that the combination of scope, timeline, and cost was in general overambitious and in several areas unrealistic.

4. Given current timeframe and assumed funding constraints, the science covers too large a parameter space and includes requirements which imply differing optimal design decisions, e.g. optimizing hardware for survey vs. single object observations. This hinders further progress in the SKA definition and converging on a conceptual design. It is an important decision for the project to either keep to the proposed timeline and adjust the scope accordingly, or keep the ambitious scope and adjust the timeline (and budget) accordingly.

5. The system engineering team did a great job in trying to satisfy the wide range of science requirements. However, the Panel did not see stable requirements which would allow a stable design for SKA. At this stage, the panel expected a higher degree of refinement regarding the SKA concept.

6. SKA is ready to move into the definition phase. This transition is essential to support the proposed timeline for a construction start (with a redefined scope), to arrive at an SKA concept, and to ensure that additional resources are focused on activities that truly support the SKA schedule.

7. The project needs to take important decisions on science and technology soon. It is recommended to define very well the process for making choices and make it very visible throughout the project. Entrust decision making to smaller groups wherever possible.

8. The Panel recommends prioritizing the science goals as soon as possible in order to enable the project to move forward with a system concept definition. This is a necessary condition to allow the definition of a SKA baseline design whose implementation would be feasible on the chosen timeline.

9. In order to enable the necessary prioritization, the Panel recommends that a suitably empowered and trusted independent Science Advisory Body should be established as soon as possible. Ideally this Science Advisory Body would consist of science authorities in astronomy who are independent of technology driven programs for SKA.

10. It is the Panel's impression that, in SKA, engineering and development goals and interests have been weighted at least equally with science goals. The Panel recommends changing this situation and making sure that the SKA be a primarily science-driven project.

11. The Panel recommends a two stage approach by defining a "baseline" SKA project and future "enhancements". The baseline SKA would be based on achieving a few top level science goals resulting from the science prioritization process. It would accommodate a mix of low risk and high risk technology and be feasible within the schedule and cost constraints. At the same time, and in view of more ambitious long-term goals, a roadmap should be planned for the introduction of innovative (higher risk) technologies which will become available at a later stage and enable wider science goals ("enhancements").

12. The Panel recommends that a Technology Advisory Body be established to assist in reaching the appropriate technology choices versus time in the process outline above. The TAB should consist of neutral experts who can assist the project to make initial technology selections and in the process of road mapping for the introduction of innovative technologies into later stages of deployment.

13. The Panel believes that - in order to enable forward planning - the output of the R&D program should be generally defined more in terms of software and hardware deliverables, e.g. detector prototypes with demonstrated performance, reliability, cost etc., rather than reports alone.

14. The Panel recommends not to underestimate the effort it will take to get from a working prototype to industrial large scale production based on the Panel's experience with smaller production quantities for ALMA and the LHC, and large quantities in industrial production. The planned time for achieving this step, currently two years for "Detailed Design, Production Engineering and Tooling" is too short in the Panel's assessment.

15. A framework for doing lifetime SKA costing seems in place. However, a detailed costing was not given, and the panel expected a more advanced costing at this stage. Stabilising requirements and producing a credible costing are quite urgent at this stage of the project. The project should not underestimate or understate the cost.

16. SKA should ensure that the SKA R&D, design work, and alternatives analysis during the project definition phase is driven by achieving cost reduction and satisfying the target total cost goals as well as the science goals.

17. The Project Director should prepare a resource plan for completing the R&D and conceptual design work needed to produce a high quality set of requirements and conceptual design report. The resource plan needs to be adequate to establish a credible construction plan for SKA including the total construction cost and sufficient information on operating costs to

inform the funding agencies of the long-term commitments needed to meet the science goals.

18. The schedule for the next two years, including the preparation of a Conceptual Design Report, should include a couple of dozen milestones with clear definitions of what it means to satisfy the milestone and the exact dates that the milestones are expected to be complete.

19. In order to achieve the schedule and resource planning goals outlined above, the project structure needs to be strengthened. The SSEC should further empower the SPDO to carry out the SKA central management, integration, and project administration functions. Success depends on the participating organizations acknowledging and supporting the central role of the SPDO. The project should start setting up the framework for institutional accountability now, e.g., MOU's with high-level authorities such as Institute Directors, Division Heads, or Department Chairs.

20. Technical effort should continue in all relevant areas: receptor design and construction of pathfinder/conceptual prototypes; site studies; systems engineering; signal transport and processing; and computing. These activities should emphasize understanding of the performance/cost implications in relation to the science goals.

Introduction

The SKA System Concept Design Review (CoDR) was convened by the Director of the SKA Program Development Office (SPDO) and was held February 24th to 26th, 2010, at the University of Manchester, Manchester, UK.

The CoDR panel consisted of an external team with broad experience from the fields of Radio Astronomy, Particle Physics, large international project collaborations, and Consumer Electronics and Semiconductors. Panel membership is given in Appendix 1, and the panel charge in Appendix 2.

This report outlines the observations and recommendations made by the Panel which were fed back to the SKA Director, the SPDO and observers on February 26th. The Panel was remarkably unanimous in their assessment and judgment.

Review Preparation

The panel was impressed by the thoroughness of the preparation for the CoDR. In particular an excellent document set was prepared and distributed in advance of the meeting which covered all facets of the project including forward plans, management process, quality standards, and underlying strategies and philosophies. Appendix 3 lists the provided documentation.

The panel members were also given the opportunity to pose preliminary questions by email and more than 100 such questions were answered prior to the meeting. This gave an excellent start to the face-to-face process and enabled the Panel to focus much more rapidly on the central considerations.

The preparatory information was felt to be at a high maturity level when considering the early phase and level of complexity of the project and this gave a lot of confidence in the SPDO-led effort.

Acknowledgement should be given to the staff in the SPDO for the standard of preparation.

The Panel also wishes to thank all participants and the SPDO for sharing all information and the open discussions.

Overall Impression

The Panel was impressed by the degree and professionalism of the SKA system engineering. The team seemed to have thought about the vast majority of the problems and have outlined strategies on how to deal with them. The only gaps which the Panel could identify concern (1) security of hardware (telescopes, arrays, receivers, etc.) at the remote sites, and (2) possible restrictions introduced by export control of high-technology items.

Every project has to deal with three main parameters: scope, schedule, and cost. It is quite common that there is some tension among these three basic parameters, and it is a measure of successful projects how well trade-offs between these three aspects are done. Concerning SKA, the Panel felt that the combination of scope, timeline, and cost was in general overambitious and in several areas unrealistic. It will be an important decision for SKA to either keep to the proposed timeline and adjust the scope accordingly, or keep the ambitious scope and adjust the timeline accordingly. ***Overall, the Panel was unanimous in its judgment that the SKA project as it was presented is too ambitious for the planned timeline and budget.***

The Panel did not see stable requirements which would allow a stable design for SKA. The majority of the Panel members expected a higher degree of refinement regarding a SKA concept. However, the definition of conceptual design seems to differ in SKA from what the panel members are used to in the sense that the SKA concept design phase is followed by a definition phase. But even at this stage, the panel expected a much more advanced definition of scope and costing.

The Panel did not see sufficiently advanced proven technologies which would show the feasibility of meeting SKA science goals within the proposed schedule and budget. There is a great deal of very promising development work underway, but much of it is insufficiently advanced to be useful in a believable budget exercise. Although the main focus of the Panel was on the organizational aspects of the program, it was clear that significant technology issues exist and generate real uncertainties for the planning process.

SKA is ready to move into the definition phase. This transition is essential to support the proposed timeline for a construction start (with a redefined scope), to arrive at an SKA concept, and to ensure that additional resources are focused on activities that truly support the SKA schedule.

Science Goals

The Design Reference Mission addresses a very broad range of science goals. In some cases, these goals require quite different capabilities from the instrument. This results in many inputs to the requirements, some even conflicting, that will likely not all be able to be satisfied in the same timeframe. The SPDO and system engineering team have done a great job in trying to satisfy the wide range of science requirements but necessarily could not present a single concept design for SKA given the variety of requirements.

To enable the project to move forward within its planned timeframe, it will be important to establish a clear focus on some specific science goals. The Panel feels that at this point the science covers a too large parameter space given current time and funding constraints. ***The Panel recommends prioritizing the science goals in order to enable the project to move forward with a system concept definition.*** Also, a simplified SKA mission statement emphasizing a few top-level science goals will help the communication process with funding agencies, the public and other parties.

In order to enable the necessary prioritization, the Panel recommends that a suitably empowered and trusted independent Science Advisory Body should be established as soon as possible. This advisory body should be asked to establish a prioritized baseline set of science goals, to allow shorter term progress to be made, but also to indicate a roadmap for enhancing the instrument over time to extend the capability to more extended science objectives. Ideally, this Science Advisory

Body would consist of science authorities in astronomy (not only radio astronomy) who are independent of technology driven programs already underway for SKA development. Ideally, the advisory body would recommend a few top level science goals, e.g. red shifted HI, which can be supported by a majority of astronomers (and funding agencies). A suitably formed Science Advisory Body would also strengthen the link between SKA and a strong and wide scientific community (which will be important for obtaining funding).

It is the Panel's impression that, in SKA, engineering and development goals and interests have been weighted at least equally with science goals. ***The Panel recommends changing this situation and making sure that the SKA be a primarily science driven project.***

Decisions on the science goals will need to be informed by readiness assessments of the various technologies. These assessments should include participation by external experts.

Recommendations

- ***The Panel recommends prioritizing the science goals in order to enable the project to move forward with a system concept definition.*** Also, a simplified SKA mission statement emphasizing a few top-level science goals will help the communication process with funding agencies, the public and other parties.
- ***In order to enable the necessary prioritization, the Panel recommends that a suitably empowered and trusted independent Science Advisory Body should be established as soon as possible.***
- ***It is the Panel's impression that, in SKA, engineering and development goals and interests have been weighted at least equally with science goals. The Panel recommends changing this situation and making sure that the SKA be a primarily science driven project.***

Technology

The project is technically very ambitious and in its present setup tries to push technology limits on pretty much <u>all</u> fronts. Some parameters are even pushed orders of magnitude beyond state-of-the-art. While a new science project should definitely aim for advancing the state of the art, the Panel felt that in the case of SKA the goals are overambitious within the given time and cost frame. Even things that traditionally have been minor problems are now an issue (e.g. power, computing, signal transport & processing).

<u>This introduces high risks. It will be difficult to successfully manage all these risks at the same time and their combined effect is likely to lead to delays and/or cost overruns. The current schedule is not felt to be realistic when considering the breadth of science goals combined with the number of new or unproven technologies to be included.</u>

The Panel recommends defining a baseline SKA project - based on a few top level science goals resulting from the prioritization process mentioned above - which enables those goals,

accommodates a mix of low risk and high risk technology, and is feasible within the schedule and cost constraints. At the same time, and in view of more ambitious long-term goals, a roadmap should be planned for the introduction of innovative technologies which will become available at a later stage. In principle, this suggests a two-stage approach (different from the two phases of a 10% SKA followed by a 100% SKA shown in the schedule). Stage 1 would implement a "baseline" SKA achievable within time and cost constraints while stage 2 would implement "enhancements" requiring technology that needs more time to come to maturity. The Panel feels it is important to engage in a focused and coherent R&D program for both the baseline and later enhancements. The timescales for particular technologies and their capability to satisfy the prioritized science goals will define the separation between the stage 1 baseline and the stage 2 enhancements. It is an important decision for the project to decide on how much risk (and budget) should be allocated to the baseline. In any case, technical maturity and cost feasibility need to be proven before committing to construction. To this end a revised plan to extend R&D should be considered.

The Panel recommends that a Technology Advisory Body be established to assist in reaching the appropriate technology choices versus time in the process outline above. The scope of this body should be along the lines given above for the Science Advisory Body, i.e. a collection of world-class experts who are sufficiently independent from the project to base their recommendations on science and technology merit, experience, risk assessment, and insight. An experienced Technology Advisory Body can also advise on the choice of appropriate separation between "baseline" and "enhancement" stages regarding technology maturity and risk.

The Panel was told that the deliverable for each DR will be a report written by the SPDO referencing the DR report and all the input documentation. While this certainly satisfies the requirements of the EC contract, ***the Panel believes that - in order to enable forward planning - the output of the R&D program should be generally defined more in terms of software and hardware deliverables, e.g. detector prototypes with demonstrated performance, reliability, cost etc., rather than reports alone.***

Recommendations

- ***The Panel recommends defining a baseline SKA project - based on a few top level science goals resulting from the prioritization process mentioned above - which enables those goals, accommodates a mix of low risk and high risk technology, and is feasible within the schedule and cost constraints.***

- ***At the same time, and in view of more ambitious long-term goals, a roadmap should be planned for the introduction of innovative (higher risk) technologies which will become available at a later stage.***

- ***The Panel recommends that a Technology Advisory Body be established to assist in reaching the appropriate technology choices versus time in the process outline above.***

- ***The Panel believes that - in order to enable forward planning - the output of the R&D program should be generally defined more in terms of software and hardware***

deliverables, e.g. detector prototypes with demonstrated performance, reliability, cost etc., rather than reports alone.

Project Definition Phase

The potential for project success is to a significant extent determined when the requirements, scope, cost, and schedule are set. SKA need to negotiate realistic user-driven and science driven requirements. Equally important is to do enough R&D to understand technical risks. The Panel recommends defining *realistic expectations* for deliverables, performance parameters, schedule, cost, contingency, etc. It will be crucial to get all stakeholders to buy-in early. The project should not underestimate or understate the cost. The early introduction of systems engineering as has occurred should be extremely beneficial. The scope, cost, schedule, etc. needs to be based on a thorough conceptual design. Explicitly define scope contingency. It is usually better to plan and implement upgrades than to implement descopes. ***The Panel's assessment is that a complete SKA conceptual design will probably take another two years to complete, ideally on the timescale of the Systems Requirements Review milestone.***

Detailed definition of requirements and scope, along with accurate cost basis and schedule durations are important. Equally important are the major planning assumptions that serve as the basis for the detailed lifetime cost and schedule estimates including: contingency requirements, inflation rate projections, currency exchange rates, commodity prices, schedule float requirements, annual funding profiles or schedule of the availability of resources, etc. In addition, the guidance provided to people preparing estimates is important, e.g., guidance on the confidence level of the estimate. ***The SPDO should prepare a list of key planning assumptions that can serve as a reference for the development of cost and schedule estimates during the project definition phase.***

Recommendations

- ***The Panel recommends defining realistic expectations for deliverables, performance parameters, schedule, cost, contingency, etc during the project definition phase.***
- ***The project should not underestimate or understate the cost.***
- ***The SPDO should prepare a list of key planning assumptions that can serve as a reference for the development of cost and schedule estimates during the project definition phase.***

Decision making

There are tough decisions on the way forward to be made in the areas of science and technology, and these decisions must be made soon. The Panel felt that it is important to define very well the process for making choices and make it very visible throughout the project.

To enable the necessary process of convergence that will allow the project to move forwards in a timely fashion it is desirable to entrust decision making to smaller groups wherever possible.

As mentioned earlier, ***the Panel recommends that decisions on both science and technology need to be informed by independent advisory bodies, e.g,. a Science Advisory Committee and a Technology Advisory Committee.***

Recommendations

- ***Take important decisions on science and technology soon. Define very well the process for making choices and make it very visible throughout the project.***
- ***Entrust decision making to smaller groups wherever possible.***
- ***Decisions on both science and technology need to be informed by independent advisory bodies, e.g. a Science Advisory Committee and a Technology Advisory Committee.***

Costing and Resources

A good framework for establishing a SKA costing was presented, and processes have been defined to estimate costs. The project seems to draw on different sources and established guidelines. However, a detailed costing was not given, and the panel expected a more advanced costing at this stage. A bottom-up system of costing needs to be established as soon as possible. The Panel understands that the lack of stability of requirements, and firming up on technology choices (driven by science choices), makes costing difficult. ***Stabilising requirements and producing a credible costing are quite urgent at this stage of the project.***

Cost reduction is a high priority R&D and design goal. The SKA proponents must find a way to reduce the total construction cost for the initial observatory. Cost reductions are possible by adjustments to scope including outright scope reductions and deferring scope to an upgrade path. There is also a need to reduce the cost of the technologies that are essential to a reduced scope option. Closure on a construction plan will require that cost reduction options are pursued vigorously so that all stakeholders are convinced that the final construction plan represents the best science value for the money. ***SKA should ensure that the SKA R&D, design work, and alternatives analysis during the project definition phase is driven by achieving cost reduction and satisfying the target total cost goals as well as the science goals.***

The investment required before construction actually begins to prepare a Construction Project Performance Baseline is substantial, typically ten to fifteen percent of the total construction cost. For very large science projects like SKA, a ten percent investment is already larger than many construction projects. The pre-construction investment is necessary to establish the credibility necessary for the project to be approved.

The Project Director should prepare a resource plan for completing the R&D and conceptual design work needed to produce a high quality set of requirements and conceptual design report. The

resource plan needs to be adequate to establish a credible construction plan for SKA including the total construction cost and sufficient information on operating costs to inform the funding agencies of the long-term commitments needed to meet the science goals.

Recommendations

- ***Stabilising requirements and producing a credible costing are quite urgent at this stage of the project.***
- ***SKA should ensure that the SKA R&D, design work, and alternatives analysis during the project definition phase is driven by achieving cost reduction and satisfying the target total cost goals as well as the science goals.***
- ***The Project Director should prepare a resource plan for completing the R&D and conceptual design work needed to produce a high quality set of requirements and conceptual design report. The resource plan needs to be adequate to establish a credible construction plan for SKA including the total construction cost and sufficient information on operating costs to inform the funding agencies of the long-term commitments needed to meet the science goals.***

Schedule

The concept design phase is to be followed by a project definition phase. During the project definition phase SKA must continue the transition to a project mode. ***The schedule for the next two years, including the preparation of a Conceptual Design Report, should include a couple of dozen milestones with clear definitions of what it means to satisfy the milestone and the exact dates that the milestones are expected to be complete.***

In comparison to previous astronomy projects, SKA will need a very large quantity of units produced by industry. High quality and extremely high reliability combined with low cost are crucial for the success of SKA. ***Based on experience with smaller production quantities for ALMA and the LHC, and large quantities in industrial production, the Panel recommends not to underestimate the effort it will take to get from a working prototype to industrial large scale production.*** The planned time for achieving this step, currently two years for "Detailed Design, Production Engineering and Tooling" is too short in the Panel's assessment.

Recommendations

- ***The schedule for the next two years, including the preparation of a Conceptual Design Report, should include a couple of dozen milestones with clear definitions of what it means to satisfy the milestone and the exact dates that the milestones are expected to be complete.***
- ***The Panel recommends not to underestimate the effort it will take to get from a working prototype to industrial large scale production based on the Panel's experience with smaller***

quantities for ALMA and the LHC, and large quantities in industrial production. The planned time for achieving this step, currently two years for "Detailed Design, Production Engineering and Tooling" is too short in the Panel's assessment.

Site Selection

There are currently two candidate sites: Australia, including New Zealand; and, South Africa, including additional countries in Africa. The SKA site decision is important to the future of radio astronomy in the long term and the regional development plans of host countries. The site selection for international science projects is typically a lengthy process. The role of SKA is to provide the decision-makers with site characterization data as well as credible construction and operations plans and realistic projections of the life-cycle implications of the SKA facility. The current plan is to select the site in 2012 and to secure significant commitments from the host countries in terms of construction resources and exclusions to future development that might adversely impact SKA operations. The plan to proceed with site selection in parallel with concept design is reasonable, but it is likely that the actual site decision will need to be informed by the completion of the conceptual design report and the preparation of a resource plan for construction.

Project structure

SKA Management Roles & Responsibilities – The Project Management plan defines the responsibilities of the SKA Science and Engineering Committee (SSEC), the SKA Program Development Office (SPDO), Domain Specialists, Liaison Engineers, Institutional Design Teams, etc. The relationship between the SPDO and the domains and the detailed responsibilities of the domain management will need to be strengthened during the project definition phase. It will be critical to realistically match responsibility for deliverables with institution, group, or individual capabilities. ***Start setting up the framework for institutional accountability now, e.g., MOU's with high-level authorities such as Institute Directors, Division Heads, or Department Chairs.*** The success of the SKA Collaborating Institutions will require being able to interact with a strong central management and integration office***. The SSEC should further empower the SPDO to carry out the SKA central management, integration, and project administration functions.***

Program Office Location and Staffing – The University of Manchester is the site of the SKA Program Development Office (SPDO). The SPDO is growing a critical mass of capability to fulfill their responsibilities as defined in the Project Management Plan. The SPDO has been successful at creating the planning documents necessary to launch the project definition phase. Further progress will require a high level of engagement with the distributed SKA R&D and conceptual design efforts. The completion of a successful conceptual design report in less than two years will require that the SPDO expands into a design group that maintains a high frequency of communication with the distributed SKA resources. Once there is a site decision there will be a transition to a Project Office at the site. This may be a long way off. ***As already mentioned in "Resources and Costing", the Project***

Director should prepare a resource plan for completing the R&D and conceptual design work needed to produce a high quality set of requirements and conceptual design report. The resource plan needs to be adequate to establish a credible construction plan for SKA including the total construction cost and sufficient information on operating costs to inform the funding agencies of the long-term commitments needed to meet the science goals.

Recommendations

- ***Start setting up the framework for institutional accountability now, e.g., MOU's with high-level authorities such as Institute Directors, Division Heads, or Department Chairs.***
- ***The SSEC should further empower the SPDO to carry out the SKA central management, integration, and project administration functions.***
- ***As already mentioned in "Resources and Costing", the Project Director should prepare a resource plan for completing the R&D and conceptual design work needed to produce a high quality set of requirements and conceptual design report. The resource plan needs to be adequate to establish a credible construction plan for SKA including the total construction cost and sufficient information on operating costs to inform the funding agencies of the long-term commitments needed to meet the science goals.***

Answers to detailed questions

To assist in forming its view of the status of the project, the Review Panel was specifically requested to consider the 11 questions which are reproduced below. Each question is followed by a summary of the Panel's comments or observations.

Question 1. Is the system framework that has been created strong enough to enable the project to move forward as a whole and is it sufficient enough to provide the necessary and clear guidance to the lower levels of the project?

It was clarified in the plenary session that "system framework" in this question refers to the technical aspects of the system rather than the project management framework.

Considering this aspect it is hard to identify what the system concept actually is other than in a very broad sense. There are system functions broadly defined within a very open framework. As technology choices have not yet been made there is no recognizable system architecture at present. There are (almost) no outline specifications for any of the subsystems.

The terminology "System Concept Design Review" leads the reader to expect that there would be a chosen architecture by the time of this milestone, but the project plan itself shows that this would not exist until later. This appears to be somewhat in conflict with normally accepted terminology.

The project management framework that has been put in place is sound and well thought through particularly when taking into account that the project is in a relatively early phase.

Question 2. At the concept level, is the system presented capable of meeting the science requirements?

As mentioned in the reply to the previous question, the system architecture is not sufficiently clear to answer this question other than in general terms.

What is clear is that the system is highly ambitious and is attempting to stretch performance by one or sometimes two orders of magnitude in several performance areas at the same time, e.g. dynamic range, collecting area and number of installations, signal processing, and computing performance. Provision of power to the instrument will also be a primary concern.

The science goals are also quite broad, requiring large frequency coverage and bandwidth, a combination of wide-field-of-view survey capability and high resolution targeted object capability, and very high fidelity and dynamic range imaging and real time performance.

These factors raise the concern that there is not a sufficiently focused mission statement to enable the project to converge on a realizable set of requirements in the near term.

It seems highly unlikely, when considering the risks of unproven technologies combined with the breadth of science goals, that the planned timescales can be met.

Question 3. Has sufficient evidence been presented for including candidate technologies to justify further resources being spent on further analysis and refinement, based on current knowledge of feasibility, cost and performance (i.e. meeting science requirements)?

It is clear that some technologies are less mature than others and the feasibility of some still needs to be proven both in performance and cost. The science goals and timeline for deployment of the instrument should be the basis for technology selection and this is a project decision. Skilful use of technology road mapping could allow the phasing in of currently less proven technologies over time if this is planned at the outset.

Question 4. Have all the necessary elements been considered or are there gaps and/or shortcomings?

The document set is very thorough in its coverage with no significant gaps. This is very impressive for this stage in the project.

Two additional points needing consideration were identified:

Security: The security of the facilities requiring a well-thought-out concept, possibly including surveillance cameras etc., has been found to be necessary at some other instruments. This is particularly important for remote, unattended stations.

Export control: The technologies in the instrument may be subject to export control and an assessment of this should be undertaken.

Question 5. Is there a sufficiently accurate estimate of risk at this stage of the project?

There is a risk register that identifies the major risks and some contingencies. There is also a methodology for the assessment and quantification of the level of risk. However, these risks have not yet been formally assessed as far as can be seen from the information presented.

Question 6. Is the plan for reducing risk credible?

No. The current breadth of the science goals combined with the very ambitious technical performance is felt to be unrealistic when viewed against the plan and timeline.

To make the plan credible the project needs to adjust either its scope (i.e. narrower science goals), or its performance ambition (i.e. only say 50% improvement on a few parameters rather than factors of 10 to 100), or its timeframe to allow the technologies to mature sufficiently.

Question 7. Are the planned decision-making processes sufficient and reasonable for carrying out the trade-offs needed to arrive at a final system design?

There are a large number of collaborators and stakeholders providing inputs to the science goals and technology development. The current governance approach is unlikely to be sufficiently focused or fast enough to allow the necessary prioritization and decision making to take place within the desired timeframe.

It would be a considerable help to appoint smaller advisory bodies consisting of neutral and trusted experts to help prioritize science goals and the process of technology selection.

A clear and transparent process for capturing, communicating, and enforcing decisions is needed.

Question 8. At what stage should descope options be considered?

Given the foregoing comment, re-scoping in some way is a high priority right now.

Question 9. Is the plan for proceeding through the subsequent project phases credible?

The plan to get to the next phase has a clear set of work packages and work breakdown structure, but is mainly expressed in terms of general FTEs per institution. Resources are in the process of coming on stream but much of this is recent. Identifying named individuals with clearly assigned responsibilities still needs to be developed but there is evidence that this is starting.

There do not appear to be any key dates so far fixed in the schedule. This needs to happen quite soon to ground the plan and make it real.

All deliverables are currently defined as documents. The Panel believes that the output of the R&D program should be generally defined more in terms of software and hardware deliverables, e.g. detector prototypes with demonstrated performance, reliability, cost etc., rather than reports alone.

Question 10. Is the schedule for proceeding to the subsequent project phases credible?

As can be seen from previous comments the combination of the breadth of science goals, high technology risks, and planned timelines are not seen as viable. Some adjustments on one or more of these fronts will be needed.

Question 11. Are resources sufficient to carry out work subsequent to the CoDR, and commensurate with the planned schedule? (People, Budget).

There is evidence that the resources into the project are beginning to ramp up. However, significant amounts of resources will be needed in the next phase to allow achieving the goals within the ambitious time scale.

Processes have been defined to estimate costs. However, there is not a bottom-up system cost estimate at present and this work is still to be done. The lack of stability of requirements, and firming up on technology choices, makes costing difficult.

Stabilizing requirements and producing a credible costing are quite urgent at this stage of the project.

Given the size of the software challenge (10-30% of total effort), starting earlier than currently planned is advisable. This is based on the observation that, in the plan, the SW development appears to run 1 - 1.5 years later than the other work streams.

Appendix 1 – Panel Membership

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Appendix 2 – Panel Charge

The CoDR was conducted to evaluate:

- The overall progress,
- Whether the technical adequacy obtained during the concept phase is at a sufficient level of maturity to allow the system to move into the next phase,
- Whether all system aspects of the project have been covered and where gaps exist, whether adequate measures have been identified to address the shortcomings.

The expected outcome of the review is the establishment of the system concept baseline by conclusion of the system level concept phase. Following the successful conclusion of the review the next phase, the system definition phase, will be initiated.

More specifically the Review Panel was requested to consider the following questions:

1. Is the system framework that has been created strong enough to enable the project to move forward as a whole and is it sufficient enough to provide the necessary and clear guidance to the lower levels of the project?
2. At the concept level, is the system presented capable of meeting the science requirements?
3. Has sufficient evidence been presented for including candidate technologies to justify further resources being spent on further analysis and refinement, based on current knowledge of feasibility, cost and performance (i.e. meeting science requirements)?
4. Have all the necessary elements been considered or are there gaps and/or shortcomings?
5. Is there a sufficiently accurate estimate of risk at this stage of the project?
6. Is the plan for reducing risk credible?
7. Are the planned decision-making processes sufficient and reasonable for carrying out the trade-offs needed to arrive at a final system design?
8. At what stage should descope options be considered?
9. Is the plan for proceeding through the subsequent project phases credible?
10. Is the schedule for proceeding to the subsequent project phases credible?
11. Are resources sufficient to carry out work subsequent to the CoDR, and commensurate with the planned schedule? (People, Budget).

Appendix 3 – Review Documentation

The CoDR Documentation Package consisted of the following documents:

Doc No	Title
1	SKA Science Case
2	Design Reference Mission (DRM)
3	SKA Science Operations Plan
4	SKA High-Level System Description
5	SKA System Requirement Specification (SRS)
6	System Interfaces
7	Environmental requirements
8	SKA strategies and philosophies (including Cost, Power, Monitoring and control, EMC, Timing and Sync, Cooling, Reliability, Availability, Maintainability (RAM), Software engineering and development, Standards, Units of measure, Infrastructure boundaries, Quality, Health and safety, Standardisation, Obsolescence, Human engineering, Life cycle definitions, Testing and verification, Change Management).
9	Risk register
10	Requirements traceability matrix
11	System Engineering Management Plan (SEMP)
12	Logistic Engineering Management Plan (LEMP)
13	Risk Management Plan (RMP)
14	Document Handling Procedure
15	Project Dictionary
16	Strategy to proceed to the next phase
17	SKA array configuration report
18	SKA site RFI environment report
19	Troposphere measurement campaign report
	Relevant reference documents