CTA Project Management Plan

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Version 1.2

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Revision History

Version	Date	Affected Sections	Author	Reason/Initiation/Remark
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1.1	23 April 2020	1.3; 2.2; 2.4.3; 2.5; 3.1; 3.4; 4.1; 4.2	W. Wild	Changes following Council and Cost Book Panel discussions
1.2	25 May 2020	4; 5	W. Wild	Update of Figures; rephrasing

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1 Introduction

1.1 Purpose of this Project Management Plan

This CTA Project Management Plan sets out the organization as well as management responsibilities and procedures to be used in the construction of the Cherenkov Telescope Array (CTA). It does not apply to the operations phase of CTA. This Project Management Plan is to be supplemented by appropriate Plans specific to areas such as Systems Engineering, Documentation Control, Quality Assurance, Acceptances, Safety and others.

1.2 Overview of CTA

The Cherenkov Telescope Array (CTA) is the next generation ground-based observatory for gamma-ray astronomy at very high energies. CTA will be the world's largest and most sensitive high-energy gamma-ray observatory covering the full sky with a northern array located at the Roque de los Muchachos astronomical observatory on the island of La Palma (Spain) and a southern array within the European Southern Observatory site at Paranal (Chile). Three classes of telescope types spread over a large area are required to cover the full CTA very-high energy range from 20 GeV to 300 TeV.

CTA is envisaged as a general-purpose observatory, the first time in this wavelength band. All previous instruments were designed, built and operated as experiments.

CTA as a concept was conceived by the CTA Consortium, an MoU based collaboration of more than 1500 scientists in about 200 institutes and 31 countries. The CTA Observatory gGmbH, a non-profit limited liability company under German law, was founded in 2014 as interim legal entity with seat in Heidelberg, Germany, for the preparation of CTA construction. The final legal entity for CTA construction and operation, a European Research Infrastructure Consortium (ERIC), is in the process of being set up with its Headquarter in Bologna (Italy) and the Science Data Management Centre (SDMC) in Zeuthen near Berlin (Germany).

1.3 Applicable Documents

The following documents are applicable to the extent specified herein. If not explicitly stated otherwise, the latest issue of the document is valid.

AD	Document Title	Document Number
AD01	CTA System-Level Science Performance Requirements	CTA-SPE-SCI-00000-0001
AD02	CTA Observatory gGmbH Articles of Association	link
AD03	Statutes of the Cherenkov Telescope Array Observatory ERIC	(being finalized by the BGR)
AD04	Cherenkov Telescope Array Observatory Cost Book	CTA-PLA-MGT-000000-0005
AD05	In-Kind Contribution Framework	Council document no48-2018, 19 June 2018

AD06	In-Kind Contribution Agreement Template	Council document no29-2019, 07 March 2019
AD07	Agreement Relating to Hosting the Northern Array of the Cherenkov Telescope Array Observatory at the Observatorio del Roque de los Muchachos (“CTA-North Hosting Agreement”)	Council document no86-2016, 09 September 2016
AD08	Agreement on the Construction, Commissioning and Operations of the Cherenkov Telescope Array (CTA) at the Paranal Site of the ESO La Silla Paranal Observatory in Chile (“CTA-South Hosting Agreement”)	Council document no2-2018, 19 December 2018
AD09	Agreement Relating to Hosting the Headquarter of the Cherenkov Telescope Array Observatory at the Bologna Research Campus (“HQ Hosting Agreement”)	Council document no74-2017
AD10	Agreement Relating to the Hosting of the Science Data Management Centre (SDMC) of the Cherenkov Telescope Array Observatory at the DESY Zeuthen Site (“SDMC Hosting Agreement”)	<doc ID>
AD11	CTA Construction Level-1 Milestones	<doc ID>
AD12	Joint Procurement Procedures for CTAO in Chile	ESO document ESO-328419
AD13	Joint Hiring and Staff Evaluation Procedure for CTAO positions on ESO contracts in Chile	ESO document ESO-331900

1.4 Acronyms and Abbreviations

Acronym / Abbreviation	Definition
ACADA	Array Control and Data Acquisition (a major software system)
ACE	Array Common Elements
AD	Applicable Document
AFC	Administrative and Finance Committee
AIV	Assembly, Integration and Verification
BGR	Board of Government Representatives (the body preparing the establishment of the CTAO ERIC)
CCB	Configuration Control Board
CRE	Change Request
CTA	Cherenkov Telescope Array

CTAC	CTA Consortium
CTAO	CTA Observatory
DPPS	Data Processing and Preservation System (a major software system)
ERIC	European Research Infrastructure Consortium (EU legal form)
gGmbH	gemeinnützige Gesellschaft mit beschränkter Haftung (German legal form)
HQ	Headquarter
ICD	Interface Control Document
IKC	In-kind contribution
IKRC	In-Kind Review Committee
KSP	Key Science Project
LST	Large-Sized Telescope
MST	Medium-Sized Telescope
OHS-E	Occupational Health, Safety and Environment
ORM	Observatorio del Roque de los Muchachos (La Palma, Spain)
PA	Product Assurance
PI	Principle Investigator
PM	Project Manager
PO	Project Office
SDMC	Science Data Management Centre (Zeuthen, Germany)
SST	Small-Sized Telescope
STAC	Scientific and Technical Advisory Committee
SUSS	Science User Support System (a major software system)
ToO	Target of Opportunity
WBS	Work Breakdown Structure

2 Project Identity

2.1 The Origins of the CTA project

The Cherenkov Telescope Array Consortium (CTAC) formed in 2008 to develop a concept for the first major open observatory for this waveband, motivated by the success of existing imaging atmospheric Cherenkov telescopes (IACTs) such as H.E.S.S., MAGIC and VERITAS. The CTA Consortium has now grown to more than 200 institutes in 31 countries.

CTA will be built and operated as a general purpose observatory for imaging the Universe at very high energies (VHE) above tens of GeV and covering several decades of the electromagnetic spectrum, improving on essentially all aspects of performance, building on the techniques and technologies demonstrated by the operating IACTs.

In 2014, the CTA Observatory (CTAO) gGmbH was founded as an interim legal entity to prepare for CTA Implementation. The CTAO Council replaced the Resource Board of agency representatives, which provided oversight of the project prior to the formation of the CTAO gGmbH.

After a comprehensive programme of site search and evaluation by the CTA Consortium from 2010 to 2013, contract negotiations for hosting CTA on the European Southern Observatory (ESO) Paranal site in Chile and at the Instituto de Astrofisica de Canarias (IAC), Roque de los Muchachos Observatory in La Palma, Spain, started. A hosting agreement between CTAO and IAC for CTA-North was signed in September 2016; and a hosting agreement between CTAO and ESO for CTA-South was signed in December 2018. The hosting agreement with DESY for the SDMC in Zeuthen (Germany) is close to signature.

In June 2016, the CTAO Council selected Bologna (Italy) as host site of the CTA Headquarters (HQ), and Berlin-Zeuthen (Germany) as host site of the CTA Science Data Management Centre (SDMC).

2.2 Project Characteristics

CTA is designed to be the first truly open VHE observatory, providing accessible data products and support services to a wide scientific community. CTA will be built with a large fraction of in-kind contributions (IKCs) provided by institutions from participating member states.

The following high-level characteristics define the main features of the CTA Observatory to be constructed, as required to address the science topics.

The CTA Observatory has the following high-level characteristics.

- Number of observation sites: Two, one in each hemisphere to cover the full sky.
- Number of telescope types to cover the 0.02 TeV to 300 TeV energy range: Three, referred to as Large-Sized, Medium-Sized and Small-Sized Telescopes (LST, MST, SST).
- Operation: The LST, MST and SST subsystems should be operable both independently as well as part of the complete system.

The CTA Observatory comprises four sites:

- CTAO Headquarters, currently in Heidelberg (Germany) and with the start of the CTAO ERIC in Bologna (Italy), hosted by the Istituto Nazionale di Astrofisica (INAF).

- Science Data Management Centre (SDMC) in Berlin-Zeuthen (Germany) hosted by Deutsches Elektronen-Synchrotron (DESY).
- CTA-North Array site at the Roque de los Muchachos astronomical observatory on the island of La Palma (Spain), with the array centre at 28.76° N latitude, 17.89° W longitude, 2177m above sea level, hosted by the Instituto de Astrofísica de Canarias (IAC).
- CTA-South Array site at Paranal Observatory in Northern Chile, with the array centre at 24.68° S latitude, 70.32° W longitude, 2163m above sea level, hosted by the European Southern Observatory (ESO).

CTA will have three types of telescopes with differing dimensions to efficiently cover the wide energy range of CTA. These three telescope sizes are referred to as the Large-Sized, Medium-Sized and Small-Sized Telescopes (LSTs, MSTs and SSTs), with approximate main mirror diameters of 23m, 12m, and 4m, respectively.

The telescope subsystem includes the telescope mechanical structure with drive motors and electronics, the optical system to collect the Cherenkov signal, and the camera to detect the signal. In order to capture unforeseeable astronomical events, the repositioning times to any point on the sky are short: less than 50 seconds for the LST and less than 90 seconds for the MST and SST. The Cherenkov cameras have typically several thousands of pixels with either photomultiplier or Silicon detector elements with an imaging pixel size of 0.1 to 0.2 Degrees.

The telescope will be installed on fixed foundations in a defined layout which has been optimized for science performance. The MSTs and LSTs will be installed both on the Northern and Southern sites, while the SSTs will only be installed on the Southern site. The telescopes are expected to be delivered as IKCs from participating institutions provided on behalf of their respective ERIC Member State.

2.3 From Experiments to Observatory

CTA will be a general-purpose observatory, the first time in this wavelength band. All previous and existing instruments were designed, built and are operated as experiments. The transition from experiments to a gamma-ray observatory with an intended lifetime of 30 years can be seen as a change of paradigm for the field and has a significant and profound impact on how to design, construct and operate CTA. In combination with the size of CTA, both technically (at least 15 times more telescopes) and organizationally (many partners and countries, four CTA sites), the construction of CTA and its project management presents quite some challenges and the need for adaptation. In broad lines, the major challenges include the following aspects:

- The CTA project needs to adopt **a way of working** which is suitable for a large and geographically distributed project and has successfully been followed in other large projects. Compared to experiments, this is probably a more formal way of working, dictated by the size and nature of the project.
- While the responsibility for IKC management and delivery is with the respective contributors, a construction project of the size and complexity like CTA needs a **strong and central coordination and management.** This is the task of CTAO Management together with the Project Office, the former to be empowered by Council to fulfil this role.
- **Systems engineering** needs to be an integral part of designing and building CTA. Well established systems engineering techniques, such as requirements management, system layout and design, interface management, configuration management, change control,

quality assurance, etc. will be applied. Especially the requirement of a 30-year lifetime for the observatory poses very high-quality requirements on the design and the hardware.

- **System simplification and standardization** become increasingly important for large projects, in particular when the construction and operation need to be carried out in the most cost- effective way. Given the design history of CTA as a bottom-up driven project with various design solutions in many areas, it is quite a challenge to converge on one solution for implementation.
- The complex and distributed nature of CTA (with many participants and countries) requires an **adequate communication and decision-making structure** throughout the project. In smaller projects usually most or all project participants share all information and participate in decision making at all levels. While this is undoubtedly a very satisfying way of working, the size and nature of CTA would quickly lead to "information overload" and to delayed or no decision making.
- The **operation of the observatory** will be done by people who – in most cases – have not designed and built the hardware and software, i.e. they are usually not experts in the used technology. This creates the need for knowledge transfer from designers and builders to the operations staff, including complete and adequate documentation (e.g. as-built technical documentation, handling and maintenance manuals, spare parts list etc.). The documentation must reflect the status of the hard- and software at any time (i.e. be under configuration control) in order to be of use to the observatory staff. Observatory type operation also means that the access to the scientific and other data, observing schedules, hardware and software is controlled and managed by CTAO, following agreed policies and procedures.

2.4 Project Environment

2.4.1 The CTA Observatory

The CTA Observatory (CTAO) is the organization and legal entity for construction and operation of CTA. The current legal form of CTAO is a gGmbH (a non-profit limited liability company under German law). The future legal form will be the CTAO ERIC under EU and Italian law.

2.4.2 The CTA Consortium

The CTA Consortium (CTAC) formed in 2008 to develop a concept for the first major open observatory for this waveband, motivated by the success of existing imaging atmospheric Cherenkov telescopes (IACTs) such as H.E.S.S., MAGIC and VERITAS. CTA will be much larger than current instruments, resulting in vastly improved performance but also specific challenges in design, construction and operation. CTAC is a MoU based collaboration with (as of 2019) more than 1,500 members from more than 200 institutes in 31 countries. The CTAC gathers the science and technology knowledge of the community and many CTAC institutions are involved in the array design and intend to supply components and subsystems to CTAO (as in-kind contributions). The CTA Consortium has also prepared a proposal for a core program of highly motivated observations, the Key Science Projects (KSPs).

The relation between CTAC and CTAO is planned to be governed by an MoU specifying the details of the cooperation during construction and operation of CTA and to be approved by the CTAO Council and the CTAC Consortium Board.

2.4.3 Contributions to Construction

Many project deliverables are expected to be supplied to CTAO in the form of In-Kind Contributions (IKC) by scientific institutions. The IKCs concern subsystems such as unit telescopes, software elements, calibration equipment, CTA-North infrastructure as well as expertise services, e.g. commissioning and science verification support, while CTAO's tasks will include central software coordination and management, the CTA-South infrastructure construction and the system integration and verification to ultimately deliver a fully functioning observatory. Table 2 (page 16) gives an overview of the major deliverables for CTA construction, either expected in-kind or by CTAO.

In allocating and managing IKCs, the Observatory is advised by its In-Kind Review Committee. An In-Kind Contribution Framework [AD05], which has been approved by the CTAO gGmbH Council in June 2018, specifies the general principles and the process for IKC allocation. Specific IKC agreements between CTAO and the contributing entity, following the IKC Agreement Template [AD06] approved by the CTAO gGmbH Council in March 2019, will cover the details of a particular deliverable.

2.5 Project Funding

The CTA construction project funding can be seen as two categories (see [AD04]): funding of IKC contributions at participating institutions, and funding of the CTAO organization and CTAO deliverables (via cash contributions).

The annual budget for CTAO, i.e. the required cash contribution, is proposed by CTAO Management and approved by the CTAO Council, after recommendation by the AFC.

The values of the various in-kind contributions, funded directly at participating institutions by the ERIC members, as well as the value of the CTAO activities, requiring cash contributions, is fixed in the CTA Observatory Cost Book [AD04].

The available amount of funding for CTA construction will be fixed in the ERIC statutes with commitments by each of the ERIC founding members.

2.6 Key Science Projects and Open Observatory

Scientific observations are categorized in regular PI proposals, Key Science Projects and Director's Discretionary Time. The Key Science Projects are large programs that ensure that the key science issues for CTA are addressed in a coherent fashion, and that produce legacy data products; they require from several 100 hours to beyond 1000 hours of observation time. The regular PI proposals submitted in response to Announcements of Opportunity, will require between a few hours and 100 hours of observation time. Director's Discretionary Time represents a small fraction of observation time reserved, for example, for unanticipated targets of opportunity.

CTAO Council will decide on the policies for access to CTA and the science data.

The scheme of Key Science Projects does not impact the construction project in the areas of hardware, infrastructure and control software, but will have an impact on the way science operations and scheduling is set up and executed.

3 CTA Construction Project

3.1 Work Breakdown Structure

The WBS for the CTA project identifies the project tasks as well as the hierarchies and dependencies of the tasks. The WBS for the construction of the Project includes the following eight level-1 tasks:

P01. Project Management
P02. Science & Science Operations Preparation
P03. Systems Engineering & Integration
P04. On-Site Construction
P05. Site Infrastructure Design & Planning
P06. Computing
P07. Telescopes
P08. Array Common Elements

The organization of the CTAO Project Office along these level-1 tasks and its relation to In-Kind Contributors is described in Section 4.2.

The scope of the level-1 tasks is as follows:

- **P01 – Project Management:**
  This task contains the central project management necessary to organise, lead and coordinate the design and construction task activities via the respective Task Coordinators in the areas of Science, Science Operations Preparation, Systems Engineering & Integration, On-Site Construction, Site Infrastructure Design & Planning, Computing, Telescopes and Array Common Elements. It includes the responsibilities for setting up and maintaining the integrated project schedule, negotiating In-Kind Contribution Agreements, managing the cash contribution, quality assurance and contributing to reporting to the Governing Bodies. This task is ultimately responsible for delivering the CTA observatory ready for science operations.

- **P02 – Science & Science Operations Preparation**
  This task provides the scientific oversight of the construction project, via the Project Scientist and the link to CTA Consortium (CTAC). It includes the responsibility for maintaining for the top-level CTA science requirements for construction and operation, safeguarding the scientific aspects of CTA, defining, planning and implementing Commissioning and Science Verification, and establishing the overall CTA calibration strategy. The Science Operations Coordinator is responsible for the preparation and setup of the CTA scientific operations from data acquisition to data delivery. This includes the (contribution to the) definition and implementation of CTA science operations policies and processes and the data workflow from the two array sites via the SDMC to the scientific users.

- **P03 – Systems Engineering & Integration**
  The CTAO Systems Engineering & Integration team, led by the Lead Systems Engineer, is responsible for executing the systems engineering (SE) work related to the overall observatory system, overseeing the SE work done in subsystem teams as outlined in the CTA Project Management Plan, and performing system integration. It includes developing and maintaining the system design including configuration and change management, system architecture and interface definition and control, system control design and system power engineering, system Reliability, Availability, and Maintainability (RAM) analysis, product design reviews and

acceptances, planning and execution of system integration and verification, and support of science commissioning and validation.

- **P04 – On-Site Construction**

  This task is led by the respective Site Managers and comprises three main areas: Infrastructure construction, integration support and preparation for operations. Infrastructure construction delivers the civil infrastructure (such as telescope foundations, roads, buildings, utility infrastructure, power distribution system, earthing grid etc.), the IT infrastructure (user networks, IT hardware and telephones, radios, surveillance system and access control), and a temporary construction camp (in the South). Integration support includes utilities cost, access / handling / transport, quality assurance inspections, and AIV and commissioning support. Preparation for operations includes the ramp up of operations staff needed at the end of construction to operate the observatory. At CTA-North, the site infrastructure will partly be a host premium and partly an IKC by the Spanish partner, while for CTA-South the site infrastructure construction will be managed and funded by CTAO.

- **P05 – Site Infrastructure Design & Planning**

  This task is responsible for specifying the site infrastructure and ensuring that the detailed designs are elaborated and within requirements, either as IKC (in the case of CTA-North) or by a CTAO contractor (in the case of CTA-South). Due to the different characteristics, nature, scale and provision schemes at the two array sites, different approaches to the infrastructure design and construction are adopted. The CTA-North site infrastructure, provided in-kind, is designed as a series of project phases, whereas the CTA-South infrastructure design has been split into elements, e.g. access road, foundations, buildings, etc. For the North site, Site Infrastructure follows up and monitors the IKC provider while at the South site the contract management will be done by the CTA-South Site Manager.

- **P06 – Computing**

  This task comprises the technical and scientific software for CTA, the needed hardware on-site and off-site and the array clock system. The CTA software architecture identifies the major software systems ACADA (Array Control and Data Acquisition), DPPS (Data Processing and Preservation System), and SUSS (Science User Support System) along with other software systems for central alarm functionality and operations support. Most software elements are expected in-kind with CTAO being responsible for the management, coordination and final release. The Computing responsibility includes the architecture, development, and delivery of on-site and off-site software and data centres for the two array sites, the CTAO Headquarter and the SDMC, except management and administrative software. Computing is also responsible for the array timing system and the necessary computing hardware to perform these tasks.

- **P07 – Telescopes**

  The telescopes are expected to be delivered as IKCs from participating institutions. This task is responsible for following up and monitoring the telescope providers concerning telescope design and construction activities, ensuring that the telescopes are delivered according to the agreed specifications and schedule.

  CTA will have three types of telescopes with differing dimensions to efficiently cover the wide gamma-ray energy range of CTA. These three telescope sizes are referred to as the Large-Sized, Medium-Sized and Small-Sized Telescopes (LSTs, MSTs and SSTs), with approximate main mirror diameters of 23m, 12m, and 4m, respectively. The telescopes will be installed on fixed foundations in a defined layout that has been optimised for science performance. The MSTs and LSTs will be installed both on the Northern and Southern sites, while the SSTs will only be installed on the Southern site.

- **P08 – Array Common Elements**
  This task is responsible for the equipment which is common to the arrays and not attributable to a single telescope, such as the Central Calibration Facility, environmental monitoring, and the Mirror Test Facility. Central Calibration activities include continuous calibration of individual telescopes' sensitivities and relative time offsets, continuous characterisation of the optical properties of the atmosphere – CTA's actual gamma-ray detector – across the observed field-of-view and from ground to the stratosphere, and monitoring of the observatory's energy and flux scales through comparison with known gamma-ray and cosmic-ray electron source spectra.

3.2 Project Deliverables

The CTA construction project will deliver the agreed configuration ready for scientific operation. The construction configuration is considered to be the previously defined "Implementation Threshold" with the types and number of telescopes as given in Table 1. It is intended to implement the Full Scope CTA configuration in the Enhancement Phase following the construction phase of CTA, subject to available funding.

		CTA Construction	CTA Enhancement
Northern Array	Number of LSTs	4	4
	Number of MSTs	5	15
Southern Array	Number of LSTs	0	4
	Number of MSTs	15	25
	Number of SSTs	50	70
Total		**74**	**118**

Table 1: Number of telescopes for each site for the CTA Construction and Enhancement phases

The Construction and Enhancement configurations differ in number of telescopes (and necessary size of the infrastructure) while the key technical deliverables for CTA construction are very similar or identical.

Expected In-kind Contributions:		
WBS	**Subsystem**	**Deliverable**
Telescopes	LST	LST structures and cameras on-site (incl. spares)
	MST	MST structures and cameras on-site (incl. spares)
	SST	SST structures and cameras on-site (incl. spares)
Computing	ACADA	Contributions to the Array Control & Data Acquisition System (ACADA)
	DPPS	Contributions to the Data Processing & Preservation System (DPPS)
	SUSS	Contributions to the Science User Support System (SUSS)
	IT & Communication	Off- and On-site Data Centre(s)
	IT & Communication	Array Clock System
Site Infrastructure Design & Planning	CTA-N Site Infrastructure	Construction of foundations, roads, power distribution, data network, operations building
Array Common Elements	Array Calibration System	Illuminators
	Array Calibration System	LIDARs
	Array Calibration System	Sun & Moon Photometer
	Array Calibration System	Atmospheric Transparency Monitoring System
	Array Calibration System	Environmental monitoring equipment
	Test Facilities	Mirror Test Facility
Construction deliverables managed by CTAO:		
WBS	**Subsystem**	**Deliverable**
Management	CTA-N, CTA-S, HQ, SDMC	Project Organization and Management, incl. Cost Book, IKC coordination, risk management, etc.
	CTA-N, CTA-S	Construction schedule
	CTA-N, CTA-S, HQ, SDMC	Project Control and reporting
	CTA	Quality Assurance
Science & Sci Ops Preparation	HQ, SDMC	Science Requirements & Configuration layout
	CTA-N, CTA-S, HQ, SDMC	Commissioning and Science Verification
	SDMC, HQ	Set-up of the off-line science operations
	SDMC, HQ	Science operations policies and plan
	SDMC, HQ, CTA-N, CTA-S	Science operations ramp-up
Systems Engineering & Integration	CTA-N, CTA-S, SDMC	System configuration & documentation
	CTA	System Requirements, WP Management, integrated system
	CTA	System Integration & Verification
	CTA	Requirements, Interfaces, RAM, Quality Control
	CTA-N, CTA-S, HQ	Technical operation and maintenance concepts and plans
	CTA-N, CTA-S	Product & System Safety implementation
On-Site Construction	CTA-N, CTA-S	On-site CTAO Organization
	CTA-N, CTA-S	On-Site construction coordination/management
	CTA-S	Infrastructure construction contract management
	CTA-N, CTA-S	Observatory technical operations ramp-up
Site Infrastructure Design & Planning	CTA-N, CTA-S	Technical Specifications, tender documentation
	CTA-N, CTA-S	Coordination
Computing	CTA	Computing requirements, architecture, WP management, integration, QA, releases, standards
	ACADA	Requirements, WP Management, integrated system, verification
	DPPS	Requirements, WP Management, integrated system, verification
	SUSS	Requirements, WP Management, integrated system, verification
	On-site & off-site ICT	Requirements, WP Management
	Array Clock System	Requirements, planning, realization, verification

Table 2: Overview of major CTA construction deliverables

3.3 In-Kind Contribution Allocations and Management

In-kind contributions will be allocated by CTAO Council decision. An IKC Agreement – to be negotiated between one or several in-kind contributors and CTAO and following the IKC Agreement Template [AD06] – will specify the details of each IKC including the form of work package management. Three different types of WP management are foreseen (Figure 1):

- **Scheme A:** In this scheme, an In-Kind Contributor is fully responsible for the management and delivery of an IKC. Contacts between the CTAO Project Office and the In-Kind Contributor or consortium are at PI, PM, and Systems, Quality and Safety Engineer level. The delivery of individual telescopes typically follows Scheme A.
- **Scheme B:** These are work packages with contributions by institutes (in-kind) and/or industrial partners under central management by the PO. The contributors are responsible for the delivery of individual parts of the overall deliverable while the PO personnel are responsible for the coordination and final assembly and delivery of the deliverable to the CTA construction project as a whole. Typical examples of this scheme are software packages such as ACADA, DPPS or SUSS.
- **Scheme C:** In this scheme the PO is fully responsible for the management, execution of the work and delivery, either with PO personnel (e.g. Systems Engineering), or with industrial contractors (e.g. CTA-South infrastructure). Funding in Scheme C can either come from the CTAO budget or directly from a CTAO ERIC Member State in which case the deliverable could be recognized as an IKC.

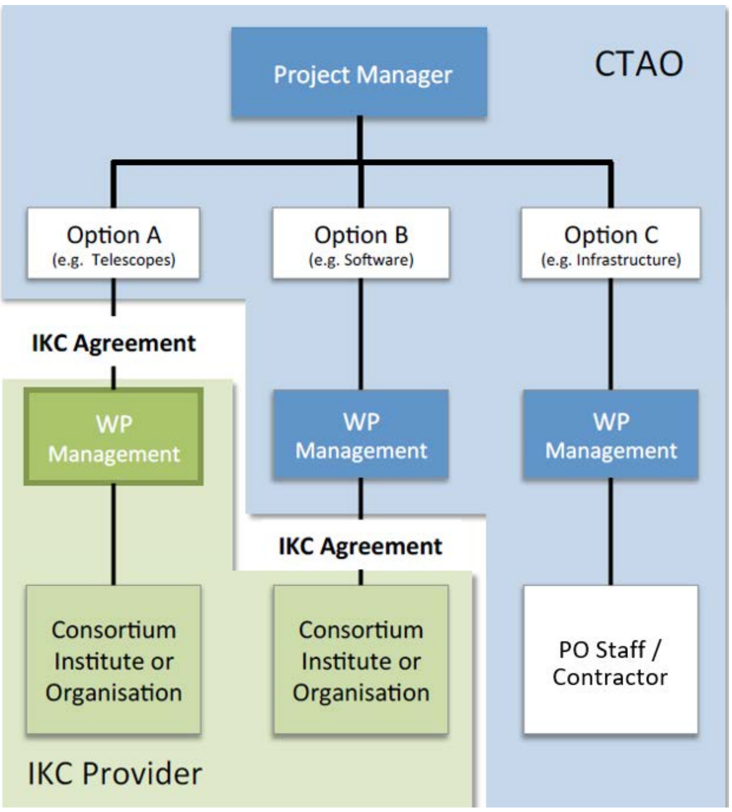

Figure 1: Schemes of work package management of the CTA construction project by CTAO. Schemes A, B, C indicate different types of work package organization. Schemes A and B refer to in-kind contributions, and Scheme C to deliverables directly managed by CTAO.

3.4 Pre-operations PI science

It is an important programmatic goal of the CTA construction project to begin taking science data as soon as it is possible. Scientific observations during commissioning of the array can: (i) make use of experienced scientists to uncover hardware and software problems so that such problems are readily identified and it is possible to implement changes to solve those problems early in the construction project; (ii) refine array instruments and techniques that depend on actual array site conditions that affect science research programs; and (iii) gain early operating experience that can be fed back to the construction project so that changes can be made to improve reliability or maintainability of the observatory.

4 Management Structure

Following a bottom-up approach in designing CTA starting after the first CTA meeting in 2006, it was recognized that a central management and legal entity is needed to build and operate the observatory. In 2014, the CTAO gGmbH (a non-profit limited liability company under German law) was founded as an interim legal entity to prepare for CTA Observatory implementation. The final legal entity for CTAO will be an ERIC under European Union and Italian law.

4.1 The CTA Observatory

The CTAO is the focal point for implementation of the CTA project. The CTAO management structure during the construction phase is shown in Figure 2.

The CTAO Shareholders (in the case of the gGmbH) or CTAO ERIC member states (in the case of the CTAO ERIC) establish the CTAO legal entity with its highest governing body, the CTAO Council. The CTAO is led by the Managing Director/Director General who reports to the CTAO Council. Council appoints the CTAO Director who in turn appoints CTAO key personnel such as the Administrative Director or Project Manager.

For CTA construction and the transition to operation, the CTAO Project Office (PO) has been created, led by the Project Manager who is responsible for delivering the agreed CTA configuration as a working observatory. In the future, a Director for Science Management and a Director of Operations will complement the CTAO.

The Council of the CTAO gGmbH has set up three advisory committees, the Administrative and Finance Committee (AFC), the Scientific and Technical Advisory Committee (STAC) and the In-Kind Review Committee (IKRC). AFC is charged with the general responsibility of advising the Council on matters of administrative and legal issues and of financial management. STAC advises the Council in scientific, technical and other related matters of importance. IKRC has been created to advise Council and CTAO Management on matters related to IKCs.

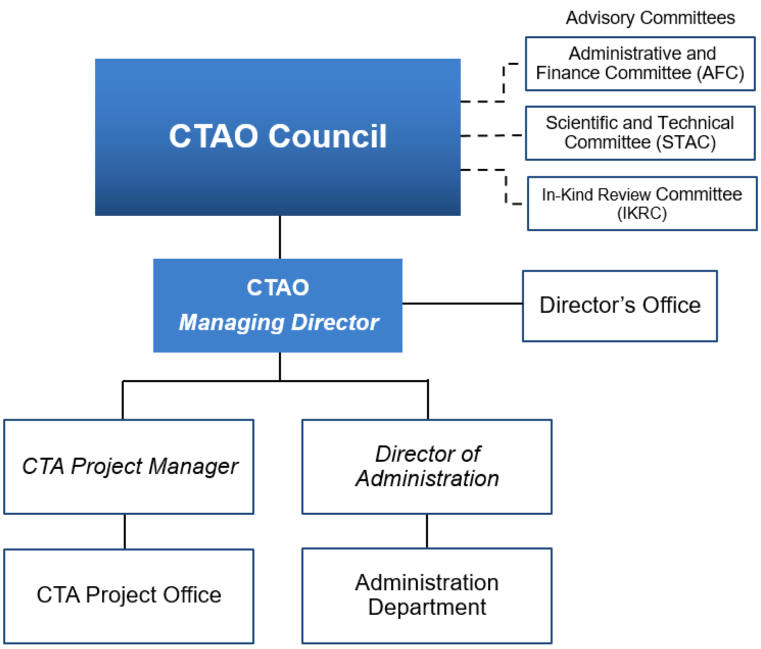

Figure 2: CTAO management structure.

4.2 The CTAO Project Office

The organization of the CTAO Project Office (PO) provides the centralized decision-making and construction project direction required to maintain the project scope and schedule and successfully manage CTA construction activities that are carried out by In-Kind Contributors and contractors. The PO will carry out its management function by specifying, in concert with the Council, the scope, schedule, and tasks of the project and coordinating and managing the efforts of the In-Kind Contributors and/or contractors to provide the necessary deliverables. The interface between the PO and the In-Kind Contributor depends on the implemented IKC scheme for a particular IKC as outlined in Section 3.3. Topics which are science related or affect the CTA science capabilities will be discussed with the CTAC and decisions will be taken by CTAO in consultation with CTAC.

4.2.1 PO Structure

The Project Office structure is shown in Figure 3. It is organized according to the Level-1 WBS tasks. Level-1 WBS tasks are led by the Task Coordinator(s) who provide the interface between the PO and the In-Kind Contributors and (in the case of the Site Managers) the local on-site construction activities. The PO is led by the Project Manager who reports to the CTAO Managing Director. The Task Coordinators report to the Project Manager and are responsible for the CTAO staff in their respective areas. Each construction work package manager, be it within CTAO, at In-Kind Contributor organizations or from industrial contractors (depending on the IKC management scheme, see Section 3.3), will be coordinated and managed by a Level-1 Task Coordinator at CTAO.

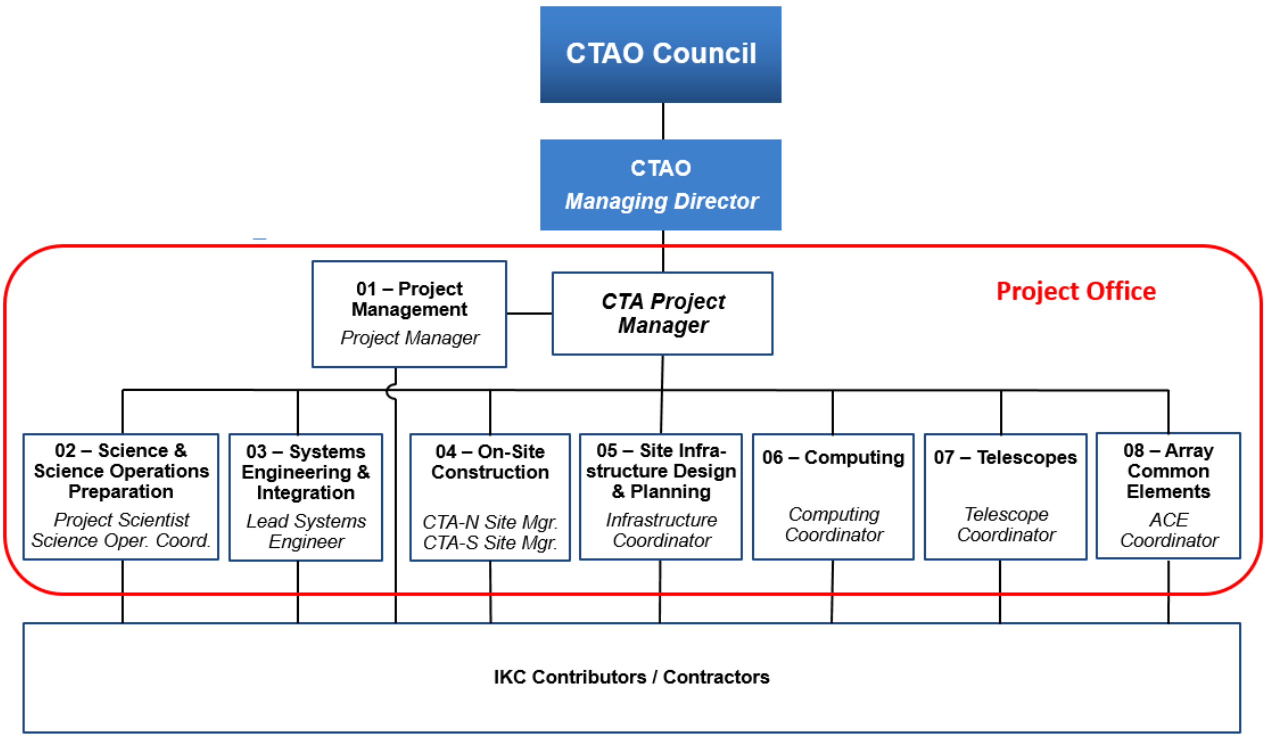

Figure 3: Structure of the Project Office and relation to the Managing Director and CTAO Council. Each level-1 task area has at least one Task Coordinator who manages the respective task and corresponding In-Kind Contributors and/or contractors.

4.2.2 Task Coordinators and Work Package Managers

There are nine Task Coordinators within the Project Office (see Figure 3): Project Scientist, Science Operations Coordinator, Lead Systems Engineer, CTA-North Site Manager, CTA-South Site Manager, Infrastructure Coordinator, Computing Coordinator, Telescope Coordinator, and Array Common Elements Coordinator.

The Work Package Managers are responsible for a defined work package and are either employed by an IKC contributor organization or CTAO depending on the work package. In either case, reporting on progress and issues of a particular work package goes via the responsible work package manager to the Task Coordinators, CTA Project Manager and Council, see Section 5.8 for details.

4.2.3 PO Responsibilities

The Project Office has the following responsibilities.

Project Scope and Schedule. The PO will:

- Maintain the top-level scientific requirements in consultation with CTAC and the technical scope of the Project. The top-level requirements and scope are intended to be approved by the Council after a CTAO proposal, taking into account input from CTAC.
- Establish and maintain the technical requirements for the CTA system. Working in conjunction with CTAC and CTA technical teams, the PO establishes the technical specifications corresponding to the top-level scientific requirements.
- Establish and maintain the Project Work Breakdown Structure (WBS), Product Breakdown Structure (PBS) and Schedule.
- Initiate and execute the IKC allocation process, negotiate the IKC agreements.
- Establish and control the CTA configuration. When the specifications or WBS must be changed, the PO controls the change process (see Section 5.4) and manages the consequences of a change. Changes affecting the Cost Book Value and/or the top level schedule (i.e. the Level-1 Milestones) need Council approval prior to implementation unless Council agrees that changes below a set value or delay period can be agreed between the CTAO Shareholder/CTAO ERIC Member State and CTAO without Council approval. This set value or delayed period will be stipulated in each IKC Agreement.
- Define, maintain, and enforce System Interfaces and Interface Control.
- Define, implement and maintain a CTA-wide Document Management System.
- Define documentation standards.
- Manage and deliver the deliverables assigned to CTAO.
- Define and execute system level integration, commissioning and science verification.

Accountability. The PO will:

- Establish and enforce acceptance criteria for delivered hardware and software.
- Be accountable to the Council for the technical management of the Project.
- Be accountable to the Council for achieving the CTA scientific requirements.

4.2.4 Project Manager

The Project Manager leads the Project Office and is responsible for the overall design and construction of the CTA Observatory. The Project Manager's duties and responsibilities include the following:

1. Write and implement the CTA Project Management Plan for the construction of CTA.
2. Lead the CTA Project Office and delegate tasks and responsibilities to the Task Coordinators as necessary.
3. Organize, direct and control the activities necessary to build and commission the CTA and to prepare operation of the CTA Observatory so that the project technical, cost and schedule objectives are met.
4. Manage and coordinate interfaces among Project Groups.
5. Manage the development of a complete description of sub-systems, components and labour for the construction of the Project in the form of the Product and Work Breakdown Structures (PBS and WBS).
6. Develop and maintain an integrated project schedule for Observatory construction.
7. Track the technical progress, cost and schedule of the project using the WBS, schedule and cost information provided by the Task Coordinators and Contributors.
8. Prepare progress reports for the CTAO Director and Council as required.
9. Negotiate the IKC Agreements with the contributors.
10. Establish and chair the CTA Configuration Control Board.
11. Manage the CTA cash contributions for CTA construction within Council-approved budgets.
12. Prepare the transition from CTA construction to operation.
13. Serve as decision-making authority for major reviews of CTA subsystems.
14. Initiate joint CTAO-ESO procurements for CTA-South as specified in [AD12].
15. Participate in the hiring and staff evaluation of CTAO PO positions including the one on ESO contracts in Chile, following [AD13].

The Project Manager is appointed by the CTAO Managing Director and serves an indefinite term. The Project Manager reports to the Managing Director.

4.2.5 Project Scientist

The Project Scientist duties and responsibilities during the construction phase include the following:

1. Complete, define, refine and maintain the top-level CTA science requirements.
2. Establish and ensure completeness of the scientific requirements for the CTA system, working in conjunction with systems engineering and the domain coordinators.

3. Provide the scientific oversight in the process of translating scientific goals into technical specifications.
4. Set scientific requirements for CTA science operations and develop the plan for science operations together with the Science Operations Coordinator
5. Be responsible for establishing the overall CTA calibration strategy.
6. Be responsible for the definition, planning and implementation of science verification.
7. Contribute to the system integration and science planning.
8. Participate in the establishment of multi-wavelength/multi-messenger needs of the observatory and the links to the corresponding facilities.
9. Ensure CTA participation in future ToO alert systems and platforms.
10. Participate in CTA reviews representing and safeguarding the CTA science goals.
11. Safeguard the scientific aspects of CTA as permanent member of the CTA Configuration Control Board.
12. Participate in the organization of scientific symposia on CTA-related science, training schools and educational PhD programs.
13. Serve as a resource and point of contact on CTA science to CTAO Outreach.

The Project Scientist reports to the Project Manager.

4.2.6 Lead Systems Engineer

The Lead Systems Engineer is responsible for project wide Systems Engineering activities and coordination at system level. The duties and responsibilities of the Lead Systems Engineer include:

1. Elaboration of the CTA system design and architecture.
2. Leadership of the CTAO Systems Engineering and System Integration team.
3. Preparation and maintenance of system configuration documents including the Technical Specifications.
4. Ensure the definition of technical interfaces at system level and their control.
5. Establish and maintain the CTA Configuration Management and place under configuration control all systems engineering documents, such as requirements specifications, interface control documents, engineering drawings, etc.
6. Preparation and implementation of key documents such as the Systems Engineering Management Plan, CTA Quality Assurance Plan, the CTA Acceptance Process, and others.
7. Define and execute overall system integration and verification.
8. Organization of technical reviews, in cooperation with the Project Manager and the relevant Task Coordinators.

9. Assist in the development and maintenance of IKC agreements and procurement contracts.
10. Establishment and maintenance of material requirements and standards.
11. Be a permanent member of the Configuration Control Board.

The Lead Systems Engineer reports to the CTA Project Manager.

4.2.7 CTA-North Site Manager

The duties and responsibilities of the CTA-North Site Manager during the construction phase include the following:

1. Assume responsibility for all day-to-day activities under CTAO responsibility at the site.
2. Hire jointly with the Project Manager the CTAO site staff.
3. Supervise the CTAO site staff and CTAO staff working at the site.
4. Manage the CTA-North construction work programme including support to system integration and commissioning.
5. Ensure implementation of the on-site Health and Occupational Safety Plan in line with CTAO’s and IAC's policies and the Spanish law jointly with the CTAO Safety officer.
6. Coordinate the parallel on-site activities in construction, commissioning and early science and manage the transition from construction to operations.
7. Contribute to the CTA-North system definition and implementation including definition of the required CTAO manpower and budget.
8. Participate in CTA project and acceptance reviews.
9. Provide the link between CTA-North and the CTAO Project Office.
10. Represent CTAO at the ORM and act as the interface to IAC and local authorities.
11. Be the contact point for local stakeholders regarding the site, including representation of CTA in the International Scientific Committee (CCI) of the Observatorios de Canarias.
12. Closely and regularly report to and discuss the course of action with the CTA Project Manager, reporting status, advancement, and issues which may have arisen.

The CTA-North Site Manager reports to the CTA Project Manager during CTA construction, and to the CTA Director of Operations during operation.

The Site Manager has the authority to exclude any individual from the CTA-North site who does not follow safe work practices. The Site Manager has the authority to refuse equipment delivered to the CTA-North site that he deems to be a hazard to safety, health or the environment.

4.2.8 CTA-South Site Manager

The duties and responsibilities of the CTA-South Site Manager during the construction phase include the following:

1. Assume responsibility for all day-to-day activities under CTAO responsibility at the site.
2. Hire jointly with the Project Manager and ESO team the CTAO site staff.
3. Supervise the CTAO site staff and CTAO staff working at the site.
4. Manage the CTA-South construction work programme including support to the system integration and commissioning.
5. Manage the CTA-South infrastructure construction work packages with their budget and the related contracts.
6. Ensure implementation of the on-site Health and Occupational Safety Plan in line with local safety regulations and procedures jointly with the CTAO Safety officer.
7. Coordinate the parallel activities in construction, commissioning and early science and manage the transition from construction to operations.
8. Contribute to the CTA-South system definition and implementation including definition of the required manpower and budget.
9. Participate in CTA project and acceptance reviews.
10. Provide the link between CTA-South and the CTAO Project Office.
11. Act as the interface to ESO-Chile and to Chilean authorities as far as not covered by ESO.
12. Be the contact point for local stakeholders regarding the site.
13. Closely and regularly report to and discuss the course of action with the CTA Project Manager, reporting status, advancement, and issues which may have arisen.

The CTA-South Site Manager reports to the CTA Project Manager during CTA construction, and to the CTA Director of Operations during operation.

The Site Manager has the authority, assigned by ESO, to exclude any individual from the site who does not follow safe work practices. The Site Manager has the authority to refuse equipment delivered to the site that he deems to be a hazard to safety, health or the environment.

4.2.9 Science Operations Coordinator

During the CTA construction phase, the Science Operations Coordinator is responsible for the preparation and setup of the CTA scientific operations from data acquisition to data delivery. Once CTA construction is completed, science operations needs to be in a state ready for (quasi-) routine operation. These setup activities will be carried out in close cooperation with the other Task Coordinators in the Project Office, in particular the CTA Project Scientist, Computing and the CTA Project Manager, and with the user community. The main duties and responsibilities of the Science Operations Coordinator include:

1. Define and – following CTAO management decisions – implement CTA science operations policies and processes, taking into account the distributed nature of CTA and in close cooperation with CTA stakeholders.
2. Define the data workflow from the two array sites to the scientific users.
3. Contribute to the establishment of the SDMC as the science operations unit within CTAO.
4. Contribute to the definition of user software requirements and needs.
5. Work closely with the CTA Project Scientist, Computing, and Systems Engineering in the definition and implementation of science operations.

The Science Operations Coordinator reports to the CTA Project Manager.

4.2.10 Infrastructure Coordinator

The Infrastructure Coordinators duties and responsibilities during the construction phase include the following:

1. Interact with CTA stakeholders to determine and document infrastructure requirements.
2. Carry out requirements, cost and schedule analysis and any other analysis studies required during construction.
3. Analyse design work needed and develop construction plans in conjunction with contracted engineers and architects.
4. Write statements of work and commission specialist engineers to support the infrastructure design process and control the quality of contractor’s work.
5. Ensure CTA infrastructure requirements, including safety aspects, are implemented during the design and construction process.
6. Support the IAC and CTA-S Site Manager in the placement and management of infrastructure construction contracts.
7. Support the verification process of the construction work according to contracts.
8. Ensure all work is fully documented to a high standard and As-Built information is recorded.
9. Demonstrate and document the fulfilment of infrastructure requirements.
10. Support the CTAO Systems Engineering team with the acceptance of the infrastructure deliverables according to contracts.

The Infrastructure Coordinator reports to the CTA Project Manager.

4.2.11 Computing Coordinator

The Computing Coordinator is responsible for the development and deployment of the CTA software and the definition of the required computing infrastructure both on-site and off-site. The duties and responsibilities of the Computing Coordinator include:

1. Lead the CTA software activities involving many partners in the CTA Consortium and industrial vendors, and in close cooperation with CTA systems engineering.
2. Lead the coordinators for the various major software elements of CTA.
3. Define the software architecture and software standards including quality management.
4. Define the technical interfaces between the CTA software packages and between the software and hardware at system level.
5. Define the project-wide software development lifecycle and environment.
6. Lead the activities towards the ICT infrastructure both on-site and off-site.
7. Conduct software reviews as needed.

The Computing Coordinator reports to the CTA Project Manager.

4.2.12 Telescope Coordinator

The Telescope Coordinator is responsible for working with the telescope IKC teams to ensure that the telescopes are delivered to CTAO within specifications and schedule. The duties and responsibilities of the Telescope Coordinator include:

1. Serve as the primary interface between the Project Office and the telescope teams.
2. Lead the CTAO Telescope team.
3. Working closely with the telescope IKC providers, ensure that the telescopes are within specifications and delivered according to the agreed schedule.
4. Support the IKC agreement negotiations for the telescopes.
5. Monitor the telescope construction work by the IKC providers.
6. Review verification plans, inspection procedures, test procedures, and analyse test and inspection reports.
7. Conduct reviews of the telescope sub-system as needed.
8. Take part in the telescope acceptance process.

The Telescope Coordinator reports to the CTA Project Manager.

4.2.13 Array Common Elements Coordinator

The Array Common Elements (ACE) Coordinator is responsible for working with the providers of central calibration equipment, environmental monitoring and any other equipment or test facility needed array wide. The duties and responsibilities of the ACE Coordinator include:

1. Serve as the primary interface between the Project Office and the ACE teams.
2. Working closely with the ACE IKC providers, ensure that the equipment is within specifications and delivered according to the agreed schedule.
3. Support the IKC agreement negotiations for the ACE deliverables.
4. Monitor the ACE construction work by the IKC providers.
5. Review verification plans, inspection procedures, test procedures, and analyse test and inspection reports.
6. Conduct reviews of the ACE elements and sub-system as needed.
7. Take part in the ACE acceptance process.

The ACE Coordinator reports to the CTA Project Manager.

4.2.14 Product Safety Engineer

The Product Safety Engineer is responsible for the safety of CTA products. His duties include:

1. Prepare, maintain and implement the CTA Product Safety Plan.
2. Manage – in close cooperation with the CTA Project Manager and Lead Systems Engineer – all safety assurance aspects of the CTA System (including software) during the Construction Phase.
3. Define applicable system safety requirements, standards and tools.
4. Coordinate the safety related interfaces with the relevant In-Kind Contributors, with ESO (for the CTA-South Site), with IAC (for the CTA-North Site), and with DESY (for the SDMC Site).
5. Convene and chair system safety related meetings.
6. Provide initial system safety program training, including CE Conformity Assessment, to the staff of the In-Kind Contributors involved in safety activities.

The Product Safety Engineer reports to the CTAO Managing Director.

4.3 In-Kind Contributors

The In-kind Contributors have a crucial role in CTA construction providing the largest part of hardware and software deliverables, either under their own management or managed by CTAO (see Section 3.3 for details). For each deliverable, key personnel of an IKC Contributor typically includes a Principle Investigator (if needed, for larger IKCs, may not be present for smaller IKCs), Project

Manager, Systems Engineer, Quality Engineer and Safety Engineer. For smaller IKCs, some of these functions may be carried out by the same person. Each of these functions will interface with the corresponding functions of the PO thus creating a horizontal communication structure among the PO and IKC at working level. At CTA project level, Integrated Teams for the various areas, e.g. Systems Engineering, Quality Assurance and Safety will be created, bringing together the responsible persons of each IKC Contributor and the PO. The PIs and PMs will regularly meet with the CTAO Director and Project Manager to ensure good information flow.

4.4 Project Communication

Efficient and effective communication in large and distributed projects is always a challenge. It is important to find the right balance for project participants and stakeholders between “I did not know” and “I hear this for the n-th time” or “I am not interested in this topic”.

During the lifetime of a project, the communication structures need to be adapted to find this balance which may change depending on the point in time in the project life cycle. In principle, a good CTA communication structure ensures that key stakeholders are informed at all times while decisions can be taken at the appropriate level in a transparent way. In principle, two general communication paths are needed in parallel: “vertical” and “horizontal”. Figure 4 illustrates the two paths.

Vertical communication in each area takes primarily place between the respective Task Coordinator in the PO and the IKC provider(s), e.g. between the Telescope Coordinator and a telescope IKC (“IKC-1” as an example in the Figure).

Horizontal communication includes project participants who have similar functions and/or expertise and/or work on the same or similar issues, e.g. the systems engineers, safety or quality engineers.

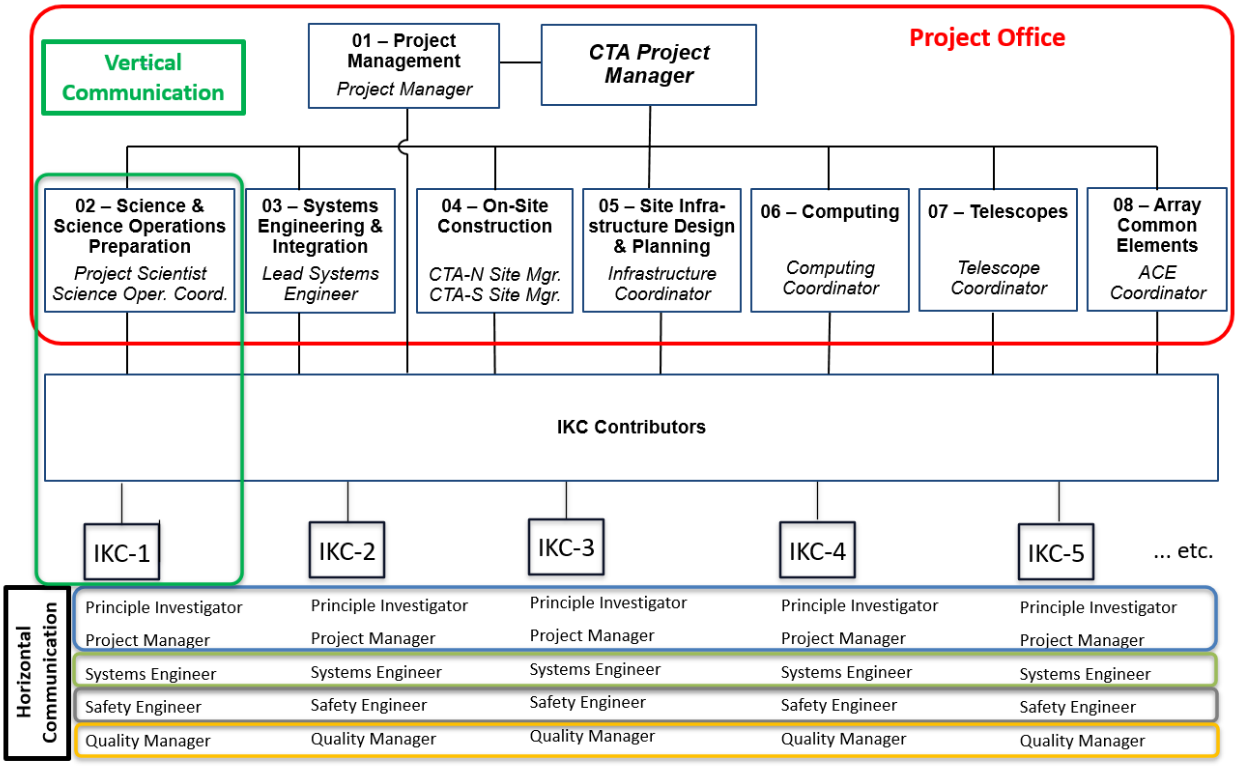

Figure 4: Communications structure between the PO and IKCs, both vertically (PO ↔ IKC) and horizontally (among PMs, Systems Engineers, etc.).

To meet the goal of appropriate communication, the following groups, meetings and mechanisms are used:

Project Committee (open session): The Project Committee (PC) open session is the forum for transmitting, sharing and exchanging information and for holding project wide technical discussions. It is organized by the CTA PM and attended by contributor technical and programmatic staff (typically PMs, Systems Engineers, Quality and Safety Engineers), the CTAO Project Office staff and CTAC representatives. It is open to any interested party within the CTA project. The intervals of PC meetings in the past (68 meetings by January 2020) and during the CTA project lifetime was quite variable from once every four to six weeks to once every few months. Following discussions between CTAO and the PC attendants including written feedback, and recognizing that much of the technical and programmatic information is also presented at the CTAC General Meetings (which are held typically in spring and autumn), the following scheme is currently implemented: PC meetings will be held about every six months, in counterphase to CTAC General Meetings, i.e. ~Jan/Feb and Jul/Sep.

Project Committee (closed session): The PC closed session is organized by the CTAO Managing Director and by invitation assembles the PIs and PMs of the (prospective) In-kind contributors. The meeting is typically held after the PC open session. In the meeting information of strategic, political and programmatic aspects are shared and discussed. Once the IKCs are allocated and the relation between CTAO and in-kind providers is formalized, this group may evolve into a kind of “CTA Coordination/Steering Group”.

Systems Engineering Group: As outlined in Section 2.3, systems engineering is of crucial importance for a project like CTA. A project wide Systems Engineering Group will ensure proper information flow and appropriate technical decision making. This group is led by the CTA Lead Systems Engineer who organizes regular meetings and telecons with the systems engineers of all IKC groups.

Other Working Groups: Topical Working Groups for certain CTA construction project aspects, such as product safety, RAM, or specific topics related to a deliverable, will be created (and possibly dissolved) as needed. The PO will create these groups in close interaction with the technical teams.

5 Management Controls

5.1 IKC Agreements

A large fraction of CTA will be provided as in-kind contributions (IKCs) by project participants to CTAO. The CTA IKC Framework [AD05], defines an IKC as “a non-cash contribution that may include:

1. a technical component as well as personnel for its assembly, installation and/or integration and technical and scientific verification,
2. personnel made available for specific tasks during the construction phase, or
3. other products or services relevant for the completion of the CTAO Facility.”

IKCs to CTA will be governed by the In-Kind Contribution Framework [AD05] and an IKC Agreement, concluded for each IKC between CTAO and the In-Kind Contributor, based on a template for the IKC Agreement [AD06].

The Framework for In-Kind Contributions is a CTAO policy adopted by CTAO Council outlining the rules for IKCs. The IKC Agreement will contains the details (e.g. Technical Specifications) and applicable procedures (e.g. Acceptance Procedures) for an IKC.

5.2 Project Management until the IKC Agreements are in place

The formal IKC allocation can only be carried out when the CTAO ERIC has been created. However, until that point in time, preparations for the construction project, in particular activities related to infrastructure design and construction, subsystem design, quality assurance, cost optimization, configuration and interface management, among others, need to proceed in good collaboration between the PO and the (prospective) IKC Contributors. The most practical (and fastest) way forward seems the implementation and application of some of the mechanisms outlined in this Project Management Plan before the formal establishment of the IKC Agreements. In the absence of any written agreement, it requires a common understanding between the (prospective) IKC Contributor and the CTAO management about the scope of a deliverable and the applicable rules for an IKC. To this end, the PO will work closely with all technical teams with the goal to move the CTA project forward, ultimately leading to IKC Agreements.

5.3 Reviews

Reviews are an integral part of the CTA construction project. They are a formalised means of technical and programmatic project assessment and an essential tool for project risk reduction. The PO will organize reviews for individual IKC deliverables as well as for CTAO deliverables. The major reviews are the following.

Preliminary Design Review (PDR). The PDR is conducted to evaluate the progress, technical adequacy, and risk resolution of the selected design approach for one or more configuration items; to determine each design's compatibility with the requirements for the configuration item; to evaluate the degree of definition and assess the technical risk associated with the selected manufacturing methods and processes; to establish the existence and compatibility of the physical and functional interfaces among the configuration items and other items of equipment, facilities, software and personnel; and, as applicable, to evaluate the preliminary operational and support documents.

Critical Design Review (CDR). The CDR is conducted to verify that the detailed design of one or more configuration items satisfy specified requirements; to establish the compatibility among the configuration items and other items of equipment, facilities, software, and personnel; to assess risk areas for each configuration item; and, as applicable, to assess the results of producibility analyses, review preliminary hardware product specifications, evaluate preliminary test planning, and evaluate the adequacy of preliminary operation and support documents.

Pre-Production Readiness Review (PPRR) / Manufacturing Readiness Review (MRR). The purpose of the PPRR or MRR is to demonstrate the overall production readiness of a supplier and assure that the items to be manufactured will meet the requirements of the Product Contract/Statement of Work and associated engineering drawings. All necessary manufacturing plans, tools, facilities and other resources shall be in place and available to ensure conformance to all quality and design requirements within the negotiated program budget and schedule.

Test Readiness Review (TRR). A TRR is usually held when the construction of a sub-system has been completed and before testing begins. The basic objective of the TRR is to check whether the test item is ready for testing (including a check that there are no open change requests or action items from previous review) and whether the test program and its related facilities are fit to perform the test (i.e. test plans and procedures are available and accepted). Generally, a TRR is planned before the start of unit, subsystem and system level acceptance or qualification testing.

Acceptance Review (ACRV). An ACRV is held for each deliverable to evaluate whether CTAO can accept the item to become part of the CTA Observatory. The purpose of an ACRV is to verify the as-built status and differences from the design specification baseline, to evaluate the test results and inspection results for compliance with specification and interface requirements, examine applicable Non-Conformance Reports (NCRs) and Requests for Waiver (RFWs), and review the Acceptance Data Package documentation. Acceptance of a particular item will be granted by the CTAO Director upon recommendation by the ACRV panel.

Operations Readiness Review (ORR). This is a CTAO review at system level to ensure that the complete system is ready for operation. A subsystem only becomes part of the operation of the Observatory when it has passed an Operations Readiness Review. This review ensures that the subsystem is in effective and stable operation, all documentation has been filed, spares are available, and the staff has been trained.

The exact scope of each review and the composition of the review panel depend on the concerned review item and its technical and organizational complexity. Details of the review organization for each of the above-mentioned reviews, such as detailed data package content, review panel composition, roles of the review chairperson(s) and review participants, decision making authority etc., will be specified in the “CTA Review Guidelines”. For each review of a particular deliverable, a specific “Review Plan” – usually elaborated by the PO and agreed with the part under review – will define the details for that particular review. Depending on the deliverable and its status, reviews may be merged for a particular deliverable to achieve the same goal in a more efficient and timely way (e.g. a CDR and MRR could be merged if all review elements are in place).

In addition to the reviews above, the In-Kind Contributors are expected to conduct their own reviews as necessary to ensure the scope and timeliness of their deliverable. The PO will assist and guide the In-Kind Contributors regarding internal reviews to ensure a high degree of consistency among the various IKC groups and deliverables.

5.4 Configuration Management

A well-defined and organized process for controlling and communicating changes throughout the complex and geographically dispersed CTA Project is essential. Configuration Management processes ensure that changes proposed are accepted only after their impacts are well understood (and accepted) and that all Parties involved in the Project are made aware of changes in a timely manner.

5.4.1 The CTA Configuration

The term "CTA Configuration" refers to all those documents that define the Project. For the purpose of Configuration Control, the CTA documents are divided into four groups:

1. Council-level documents
2. Project-level documents
3. IKC-level documents
4. Non-controlled documents

Configuration Control acts on the documents that define the Project. The process that is used depends on the type of document to be controlled.
Configuration Control is made up of four main elements:

1. A means of formally requesting a change;
2. A process for analysing the technical, performance, schedule and cost impacts of the proposed change;
3. A process for making a decision concerning the change;
4. A process for communicating that decision.

The application of these elements to each of the four types of CTA documents is as follows:

- Council-level documents include – among others – the Hosting Agreements [AD07] to [AD10], the CTA Cost Book [AD04], IKC Framework [AD05], IKC Agreement Template [AD06] and the CTA Construction Level-1 Milestones [AD11]. Changes to Council-level documents can be requested by Council members and require direct action by the CTA Council; it is the responsibility of the CTAO Director to implement changes approved by the Council.

The CTA Project Manager defines which documents are Project-level documents and then determines when a version of each document is to be submitted to the Configuration Control Board (CCB) for placing it under configuration control. Once under configuration control, a document can only be changed after a formal change request and a positive decision by the CCB. All change requests must be presented to the CCB.

- Project-level documents include the top-level engineering requirements for each major subsystem, the technical Design Reports (TDRs) and Interface Control Documents (ICDs) between subsystems that cross IKC or WBS boundaries. Change Requests (CREs) to project-level documents can be initiated by any of the work package or work element managers and require action/approval by the CCB.

- IKC-level documents include detailed drawings and documents of an allocated IKC, including IKC internal interfaces, and are intended to implement the contents of project-level documents. Control of these documents is the purview of the IKC management. It is the responsibility of the IKC management to ensure that these documents are consistent with all applicable project-level documents.
- Non-controlled documents – in the framework of CTA construction configuration control – include CTA publications and other documents that do not officially define the Project. Baseline and change authorization for these documents depends on the document type, but all such documents and processes are outside CCB control.

5.4.2 Configuration Control Board

A Configuration Control Board (CCB) will be established and will be responsible for managing changes to all project-level documents. The CCB is chaired by the CTA Project Manager. A person designated by the CTA Project Manager, e.g. a senior member of the Systems Engineering Group, will serve as the CCB Secretary.

In addition to the CTA Project Manager, the CCB shall consist of the following permanent members:

- Lead Systems Engineer
- CTA Project Scientist
- Product Safety Engineer

Additional temporary CCB members will be added at the discretion of the CCB Chair for particular issues which needs consultation with an affected party, e.g. an in-kind contributor. This is typically the case when a Change Request affects an IKC, in which case the responsible IKC project manager and/or systems engineer shall be included in the CCB for that particular issue.

In any case, as noted below, the CCB solicits input from all concerned Task Coordinators prior to considering a requested change. It is anticipated that most actions will be carried out by consensus of the CCB members. If efforts to reach consensus fail, a vote of the members will be necessary. Meetings and votes of the CCB can be carried out in any manner selected by the Chairman including, but not limited to face-to-face meetings, audio or video teleconference, email correspondence or telephone polling.

The CTAO Director has the authority to rescind actions of the CCB by informing the CTA Project Manager and the CTA Council.

As stipulated in [AD05], all changes affecting the Cost Book Value and/or the overall schedule will need Council approval prior to implementation unless Council agrees that changes below a set value or delay period can be agreed between the Shareholder and CTAO without Council approval. This set value or delayed period will be stipulated in each IKC Agreement.

5.4.3 Changes within an IKC

It is the responsibility of an In-Kind Contributor to manage changes at IKC level in consultation with the CTAO Project Office. This means that any intended IKC level change will be communicated by the In-Kind Contributor to the Project Office while it follows an IKC internal process for raising, evaluating and approving a change request. In any case, an IKC level change needs to be in compliance with the relevant IKC Agreement and consistent with all applicable project-level documents, such as performance requirements, specifications, standards and ICDs.

5.5 Quality Assurance

The quality policy of the CTA construction project is to build the CTA Observatory as a defect-free gamma-ray observatory that fulfils all requirements in order to be operated efficiently with a high availability and that is capable of satisfying the scientific community's needs. That policy has been translated into the following specific quality objectives:

- Support the design of products for meeting all requirements.
- Support the production processes for keeping them under control and capable of producing products that fully meet the requirements.
- Support the procurement processes for obtaining products from external suppliers that are free of defects and which meet all the requirements.
- Prevent non-conforming products being delivered to the CTA.
- Resolve and minimize quality problems, guiding the improvement process for eradicating the cause of non-conforming products.
- Keep control of project documentation and maintain its quality.

Within CTAO during the construction phase the Quality Officer will be responsible for maintaining and executing the CTA Quality Plan that will be an applicable document for all IKC framework agreements and other suppliers. The quality plan details the processes – such as quality system audits of the suppliers, configuration management, quality control, and non-conformance handling – that will be used to meet the quality objectives.

The In-Kind Contributor's responsibility for the design, manufacturing and AIV of the allocated IKC includes the full responsibility for the subsystem QA activities. The IKC Agreement Template [AD06] specifies that the QA requirements form an integral part of the IKC agreement between the CTAO and the In-Kind Contributor.

The CTAO Quality Officer will work with the IKC suppliers' management and quality organisation to ensure that their quality processes adequately address the CTA quality objectives. As part of quality control in the acceptance process, the CTA Quality Officer will organise or execute inspections at the premises of equipment suppliers and on-site in coordination with the Systems Engineering & Integration team and site managers and will participate in acceptance events. This Officer will run the non-conformance resolution process and oversee the investigation of any major failures.

5.6 Budget and Cost Control

A large fraction of CTA will be provided as in-kind contributions. As pointed out in Section 2.5 the CTA construction project is funded via IKC contributions from participating institutions, and funding of the CTAO project (and organization) and CTAO deliverables via cash contributions.

The budget and spending authority for a particular IKC remains with the contributing entity which is also accepting the cost risk for an agreed IKC. The budget process for an IKC follows the internal rules of the relevant In-Kind Contributor(s). Resource and cost control for an IKC shall take place at In-Kind Contributor level. Budget depletion shall be regularly reported to CTAO Management.

The CTAO budget includes the funds for running CTAO and the funds for those CTA construction items and activities which are not provided as IKCs.

5.7 Schedule Control

Schedule definitions are currently under revision. The baseline schedule is controlled at the level of the Council.

Level-1 Milestones will be specified by the PO and approved by Council which must also approve all changes to Level-1 Milestones. The PO will establish and maintain a project master schedule based on Level-1 Milestones. Each Task Coordinator will build up a set of Level-2 Milestones for which it is responsible, consistent with the Level-1 Milestones. Each Work Package Manager will develop and maintain a set of Level-3 Milestones for their work packages, consistent with Level-2 Milestones. Schedule status will be reported up through the project organization from work package managers to Task Coordinators, to the PM, CTAO Director and finally to the Council.

Schedule control of IKCs is the responsibility of the In-Kind Contributor. Imminent deviations from the agreed milestone or delivery schedule shall be reported to the PO as soon as they become apparent. The In-Kind Contributor and the PO shall jointly look into the remedy of delays or other schedule issues. Details of the schedule control for a particular IKC will be agreed upon in the corresponding IKC Agreement.

5.8 Management Reporting

Once IKCs have been allocated and CTA construction has started, regular reporting on technical progress and programmatic issues will be implemented. While the budget, cost and detailed schedule control for each IKC is the responsibility of the IKC Contributor, information on these items will be made available to the PO and Council including its advisory bodies.

The Work Package Managers will provide a monthly report of technical, schedule and resource status including financial information to the relevant Task Coordinator. The Task Coordinators will conduct periodic reviews of the status of the work packages for which they are responsible and provide a summary report to the CTA Project Manager. Each Work Package Manager and Task Coordinator will present the technical, schedule, and financial issues that will affect their ability to achieve their goals of the work packages for which they are responsible. The CTAO Director will provide regular reports of the project status to the Council.

5.9 Acceptance

Each deliverable to CTAO for the Project, either by an In-Kind Contributor or by an industrial contractor to CTAO, will undergo a formal acceptance process including an Acceptance Review.

As laid down in [AD05], acceptance will follow general acceptance procedures defined and implemented by CTAO. In general, the acceptance process can have two steps:

1. Provisional Acceptance of an In-Kind Contribution by CTAO which takes place at the Contributor's site before delivering the IKC to the respective array site;
2. Final Acceptance at the CTA Observatory site, granted by CTAO.

Final Acceptance is the formal recognition by CTAO that an In-Kind Contribution is compliant with the relevant requirements and interface specifications, safety regulations and delivery of all agreed deliverables as specified in the In-Kind Contribution Agreement and the applicable Acceptance Plan. Any agreed warranty period for a particular item will start with final acceptance of that item. For each finally accepted item CTAO will issue an Acceptance Certificate.

CTAO will organize the Acceptance Review together with the In-Kind Contributor or contractor. Details will depend on the deliverable and the acceptance location and will be specified in the Acceptance Plan for a particular deliverable.

For the acceptance of deliverables for CTA-South in Chile which have been procured by ESO at the request of CTAO (e.g. CTA-South infrastructure deliverables), the “Joint Procurement Procedures for CTAO in Chile” [AD12] shall apply.

6 Product/System Safety and Occupational Health, Safety and Environment

CTAO is responsible for delivering an observatory which complies with applicable safety regulations. A Product/System Safety Engineer and an Occupational Health, Safety and Environment (OHS-E) Officer are needed to fulfil these legal obligations at Corporate Level and at the different CTAO sites.

Construction activities for IKCs will either take place at existing organizations (university and research institutions) with established safety and health policies and regulations, or at the observatory construction sites on La Palma and in Chile for which local safety and health policies and regulations are applicable.

The CTAO Product Safety Engineer is responsible for developing a Product Safety Plan which is applicable for the entire project life cycle from the start of the Preliminary Design Phase, covering construction and operation and up to the dismantling of the individual products. The Product Safety Plan defines the applicable regulations, rules and procedure necessary to guarantee the compliance of the entire CTA System with the European Union safety regulations. These regulations are also adopted by ESO for the equipment safety at all ESO territories.

The Product Safety Plan must be released by the CTA Project Manager and the CTAO Managing Director. It is applicable to all CTA components including the IKCs.

The Product Safety Plan does not include the locally applicable office (HQ or SDMC) or construction site (in La Palma and Chile) safety or Occupational Health, Safety and Environment aspects (OHS-E aspects). These will be covered by separate documents (e.g. CTAO Safety Policy and Organisation) developed by the CTAO Safety and Health Officer, under the responsibility of the Managing Director.