CTA Power Requirements

This Version:				
Ver.	Created	Comment	Distribution	Corresponding...
0.2	2018-04-13	Addition of Associated Requirements	CTA	Editor: *See Appendix 3.1 Checker: ________ Approver: ________

Keywords:
CTA; Software; LST;

Version History:				
Ver.	Date	Comment	Distribution	Corresponding...
0.1	2018-01-22	First draft	Power Concept Review	*See App. 3.1

Table of Contents

1 Introduction

The Cherenkov Telescope Array (CTA) is a multi-national endeavour to build the next generation observatory for very high energy astronomy. The concept and scientific case for CTA are outlined here: [1, 2]. CTA will be split across two sites (at Armazones, Chile in the Southern hemisphere, and La Palma, Canary Islands in the Northern hemisphere), abbreviated as CTA-S and CTA-N. At each site, there will be an array of telescopes, of up to three different sizes; Large, Medium and Small Sized Telescopes (LST, MST, SST) with Small telescopes deployed at the Southern site only. The planned telescope array layouts are given in [3] for CTA-S and in [4] for CTA-N. Both sites will have specific power needs, and the overall concept is introduced in [5].

This document serves to summarise the CTA requirements that are specific to the power system and power consumption needs. In addition to those requirements listed here, all CTA systems (including power) are subject to a set of common requirements covering safety, maintenance and occupational hazard aspects, in compliance with the applicable regulations of the host countries.

At each CTA site, in addition to telescopes, there are a number of central buildings and facilities needed for the operation of the array, as well as auxiliary devices, all of which have corresponding power needs. The number of telescopes operating at each site is given in table 1.1.

For each telescope, the power consumption requirements are split between requirements on the Telescope Structure and requirements on the Cherenkov Camera. These are defined as:

Telescope Structure: All of the hardware and software associated to a single optical telescope capable of pointing to different parts of the sky and collecting light on to a Cherenkov Camera. A Telescope Structure forms part of a Cherenkov Telescope System. Telescope Structure may be abbreviated as 'Structure'.

Cherenkov Camera: All of the hardware and software associated with Cherenkov image detection, digitisation, transmission and pre-processing. A Cherenkov Camera forms part of a Cherenkov Telescope System, and has as its principle elements a Camera Unit and software deployed on a Camera Server.

Power consumption due to the Camera cooling system is included in the Camera budget, however the power consumption of the Camera Server is excluded. This contribution forms part of the power needs of the on-site Data Centre. In the case of the LSTs, a dedicated energy storage system is envisaged, to supply the extra power for peak consumption (associated with rapid repositioning), which will need to be recharged from the grid. The power consumption by the energy storage system is included in the Structure budget for the LSTs.

All Telescopes will operate according to a common state machine, comprising the following states: Off, Safe, Standby, Ready and Observing forming the main control sequence, with Fault and Engineering

	CTA-N	CTA-S
LST	4	4
MST	15	25
SST	–	70

Table 1.1 – Number of telescopes at each CTA site in the baseline design.

states for maintenance / additional purposes. The state definitions are:

Off State: The System is entirely without electrical power.

Safe State: The System is in a configuration suitable for survival in extreme conditions, minimising use of power whilst still providing basic status monitoring, and maximising the instrument lifetime.

Standby State: The System is in a state which is still safe with respect to extreme conditions, but has all components activated, with preparations for Observation initiated. Internal calibration activities may take place.

Ready State: The System is prepared for rapid entry in to the Observing State. Internal calibration activities may take place.

Observing State: The System is an a state associated with observatory data taking, with configuration dictated by performance requirements. Calibration activities may take place.

Fault State: The System has encountered a serious problem which means it is currently unable to reach one of the standard States.

Engineering State: The System is in a state designed to facilitate maintenance and engineering activities, and is unavailable for scientific operations.

Note that the Safe State configuration must be defined for a given Telescope design to ensure survival conditions can be endured without damage, the details of the configuration may vary between telescope designs. When in the Safe state, it may be assumed that power is available at each telescope up to the levels specified below. In addition, it may be assumed that Telescopes will be unlikely to spend longer than 48 hours continuously in the Off State during the operations phase, or 1% of the total time. It is anticipated that the Off State is only entered for maintenance purposes or under exceptional circumstances, such as adverse environmental conditions.

In the Standby State, it is expected that Cameras are warming up, yet the Telescope Structure is parked, whereas in the Ready State, the Telescope Structure is unparked.

Based on data taken at the CTA sites (La Palma in the Northern hemisphere and Armazones, Chile in the Southern hemisphere) [6], environmental conditions exceeding the Observing conditions range (i.e. falling into the survival conditions category) may be expected to occur for $\sim$1% of the time annually. Telescopes are expected to be capable of data taking under astronomical darkness and low moonlight conditions, up to a night sky brightness of up to $5\times$ that of an astronomically dark sky. SSTs at CTA-S, however, are expected to continue data taking up to a night sky brightness of $30\times$ that of astronomical darkness.

The fraction of time expected to be spent in each state is used to calculate the annual power usage of both sites, as well as to estimate the average consumption.

2 Power Requirements

2.1 Telescope Requirements

For each Telescope Structure and Cherenkov Camera, a set of four requirements are allocated covering the average and peak consumptions in the Observing and Safe states. The text of these requirements are listed below, whilst the values are given in table 2.1.

	Observing State	Safe State	Observing State Peak	Safe State Peak
LST Structure	11 kW	5 kW	30 kW	11 kW
LST Camera	11kW	5 kW	18 kW	11 kW
MST Structure	5 kW	0.5 kW	24 kW	4 kW
MST Camera	11 kW	2 kW	11 kW	3 kW
SST Structure	4 kW	0.5 kW	11 kW	2 kW
SST Camera	3 kW	0.5 kW	4 kW	1 kW

Table 2.1 – Power allocations for the Telescope Power Requirements.

Telescope Type	Observing Average	Safe Average
Combined LST	22 kW	10.2 kW
Combined MST	16 kW	1.6 kW
Combined SST-1m	6.8 kW	0.52 kW
Combined SST-GCT	2.5 kW	0.43 kW

Table 2.2 – Combined average power consumptions using values corresponding to current telescope designs. Two sets of values are given for SSTs, indicating the upper and lower bounds for SST power consumption.

– **B-xST-0610 / 1580 Average Power Consumption during Observations**: The average power consumption by a single xST Structure/Camera during Observations must not exceed X kW.

– **B-xST-0640 / 1600 Annual Average Power Consumption in the Safe State**: The average power consumption over a full year by a single xST Structure/Camera in the Safe State must not exceed X kW.

– **B-xST-0620 / 1570 Peak Power Consumption during Observations**: The peak power consumption by a single xST Structure/Camera during Observations must not exceed X kW.

– **B-xST-0630 / 1590 Peak Power Consumption in the Safe State**: The peak power consumption by a single xST Structure/Camera in the Safe State must not exceed X kW.

where the proposed power budget is split into Structure / Camera consumptions of X kW given in table 2.1. Note that during Observations, Structures and Cameras may also be in the Ready State. Peak consumptions are expected to occur in the Observing State due to Telescope repositioning and in the Safe State due to adverse environmental conditions (see [6]).

Values given in table 2.1 correspond to the proposed maximum Telescope power consumption limits. The projected average consumptions for specific current telescope designs, combined between Structure and Camera, are given in table 2.2.

The average consumption for the Observing State for Telescope Structure and Camera combined is calculated based on assuming one repositioning using peak power per hour, lasting for $\sim$ half of the required transition time. Note that the required transition times are 30 s for LSTs, 90 s for MSTs and 70 s for SSTs, to slew to any position on the sky; we assume that the slewing distance averages about half the maximum distance. The average consumption for the Safe State for Telescope Structure and Camera combined is calculated assuming that 1% of the total time per year is spent in extreme conditions (adverse environmental conditions needing high power consumption). The average consumption for the Standby State is assumed to correspond to the Camera power usage during the Observing State (Cameras will typically be warming up / conducting calibration) and the Structure power usage during the Safe State (Structures remain parked).

Note also that the combined values, used in calculating the total annual energy consumptions in section 2.2, are calculated using values taken from telescope designs and not the values given in table 2.1, such that the combined total may be less than the sum of the required power values.

State	Conditions	No. Hours (CTA-S)	No. Hours (CTA-N)
	dark	1593	1564
Observing	$5\times$ dark	804	788
	$30\times$ dark	875 / 0	–
Standby	any	715 / 663	663
Safe	any	4779 / 5706	5751

Table 2.3 – Number of hours per year available for observations under the corresponding conditions; for high NSB, the additional number of hours with respect to the previous category is given. Time spent in the standby state is dominated by the time needed for Cameras to warm up prior to observations commencing. When not observing or in the Standby state, it is assumed that telescopes are in the Safe state. For CTA-S, where two values are given, the former corresponds to SSTs and the latter to LSTs and MSTs. An average number of 8766 hours per year is used.

Requirement	CTA-South	CTA-North
Annual Energy Consumption	4.4 - 5.4 GWh	2.6 GWh
Power during Observations	0.9 - 1.3 MW	0.55 MW
Peak Power Consumption	1.8 - 2.5 MW	1 MW

Table 2.4 – The power consumption by each of the CTA sites under the corresponding conditions must be less than the values given here. The ranges given for CTA-South correspond to the expectation for different SST designs, with the requirement given by the upper bound of the range.

2.2 Power Infrastructure Requirements

The total energy consumption per year at each site was calculated based on the expected amount of observing time and time in the safe state, assuming a frequency of peak power consumption of 1% of the total time per year due to adverse environmental conditions.

For each site of CTA, there are power requirements on the total annual consumption, the average power consumption during observations and the peak power consumption. The final power system design is driven primarily by the projected peak consumption; the values given in table 2.4 include a 10% margin above the expected peak consumption at each site, based on current prototype designs. The text of these requirements are listed below, whilst the values for both sites are given in table 2.4 (see also 3.1).

- **B-INFRA-0500 / 0530 Peak Power** The southern / northern site infrastructure must be capable of providing the peak electrical power required for observatory operation of X MW at the required power quality. Peak consumption occurs due to simultaneous movement of telescopes in adverse wind conditions, expected to last at most 2 minutes and occurring at most 10 times per night.
- **B-INFRA-0510 / 0540 Power during observations** The southern / northern site infrastructure must be capable of providing the average electrical power required for observatory operation during observations of X MW at the required power quality.
- **B-INFRA-0520 / 0550 Annual Energy Consumption** The annual power consumption of the southern/northern site is expected not to exceed X GWh.

These are calculated based on the expected number of observing hours per year (given in table 2.3), assuming a maximum power consumption scenario whereby observations take place for the maximum possible time each year, whilst incorporating the required Telescope availability. For LST and MST, this includes observations up to $5\times$ dark NSB, whilst for SST observations up to $30\times$ dark NSB are used. A peak consumption occurrence of half of the required repositioning time once per hour is assumed. A peak Safe state consumption of 1% of the total annual time (corresponding to extreme environmental conditions) is also used. Times given in table 2.3 are combined with the telescope combinations given in table 1.1 and their respective projected power consumption needs in table 2.1. The resulting values are given in table 2.4.

As an example, the required power during observations for CTA-N is given by the total for the different telescopes: for LSTs, this is the projected average consumption for an LST in the observing state (22 kW, table 2.1) multiplied by the number of LSTs (4, table 1.1). Similarly, for the MSTs in the Observing state, the total is for 15 MSTs at 16 kW each. An additional allowance for the technical buildings (150 kW), auxiliary devices and distributed infrastructure (15 kW total) is included in the required array power during observations. This gives a combined total of $(4 \times 22) + (15 \times 16) + 150 + 15 = 493$ kW. The requirement of 0.55 MW (see table 2.4) is then set allowing for at least a 10% margin above these projected needs.

The total annual energy consumption for a given site is obtained by combining the total expected consumptions in the observing, safe and standby states respectively. The Observing State values for the different telescopes above are used in combination with the total number of hours available for observations per year (table 2.3) and the required telescope availability (95% for LSTs, 97% for MSTs and SSTs). For the Standby State, it is assumed that telescopes spend $\sim$ 2 hours each night in this state (warming up, performing calibration), with no observations occurring on 2% of the nights per year due to clouds / adverse conditions, and with no warm up of LST / MST for $\sim$ 2 nights per moon cycle. It is assumed that telescopes are in the safe state, with average safe state consumption needs, for the remaining time during which they are not in the Observing or Standby states. To the Safe state estimate, we include that peak Safe State power consumption may be expected to occur for $\sim 1\%$ of the time (with average Safe State power consumption for the remaining time). To all estimations, auxiliary devices and distributed infrastructure are included, along with power needs for technical facilities and buildings located on-site. This gives a projected annual energy consumption of 4.26 GWh for CTA-S and 2.51 GWh for CTA-N (table 2.4).

Note that the power consumption values given in table 2.4 are adequate for the telescope designs with the highest projected power needs at the current time. Use of alternative telescope designs can be expected to reduce these values.

Power consumption requirements applying to the central observatory infrastructure and facilities are as follows (see also 3.1):

B-INFRA-0580 / 0585 Technical Building Power: Technical buildings and facilities located at the CTA-N (S) site must be compliant with the allocated power consumption budget of 150 kW (240 kW).

B-INFRA-0590 /0595 Central Infrastructure Power: The total peak instantaneous power consumption by all distributed hardware (OES controllable systems) and Interface Cabinets deployed within the array must never exceed 15 kW (CTA-N) / 48 kW (CTA-S). The average (over timescales of at least 10 minutes) total power consumption must not exceed 11 kW (CTA-N) / 40 kW (CTA-S).

Note that this budget is for the technical buildings expected to be operational on-site; it is assumed that accommodation for CTAO personnel is located in nearby buildings not belonging to CTAO and does not form part of this budget. Similarly, additional technical facilities which may be located off site and are therefore not included in the current site planning, such as a mirror re-coating facility, are also not included in this budget. If a mirror re-coating facility is included in the power system design, the corresponding power needs would be increased accordingly. The on-site Data Centres are estimated to consume $\sim$100 kW at CTA-N, and $1.5\times$ this at CTA-S (150 kW). Both sites are expected to host a Camera Testing Facility, such that the power consumption of a Camera can be added to the Technical Building needs. The remaining estimate includes standard building power consumption, air conditioning for a UPS system and use of low power tools in mechanical workshops. It is anticipated that the use of mechanical power tools with high consumption needs is restricted to day time activities, such that power usage due to technical and maintenance activities does not contribute to the peak load (expected to occur at night time).The total building power needs for CTA-S is also expected to include the power needs of an outreach visitor centre. Each of the Interface Cabinets deployed (one per Telescope and OES controllable system) is anticipated to require $\sim$300 W of power, for a total of 6 kW at CTA-N, and 30 kW at CTA-S.

In addition, the following set of requirements apply to the power distribution system (see also 3.1):

– **B-INFRA-0505 Power Upgradability**: Provision must be made for a possible upgrade of the peak power provision to both CTA sites, to accommodate extensions, by an additional 40%. *The baseline peak power provisions are given in B-INFRA-0500 (CTA-S) and B-INFRA-0530 (CTA-N).*

- **B-INFRA-0560 Backup Power**: Both sites of the CTA Observatory must have suitable backup power supplies as redundant systems which ensure that at least enough power is available to move all telescopes to the parking position in case of external power failure and the power needed to ensure the safety of personnel.
- **B-INFRA-0570 Power Distribution**: The nominal voltage of CTA three-phase low voltage power systems reaching the telescopes and buildings of (both sites of) the CTA Observatory must be 230/400 V, with 230 V being the phase-to-neutral and 400 V the phase-to-phase voltage. The nominal frequency of CTA power systems must be 50 Hz.
- **B-INFRA-0600 Power System Adaptability**: The on-site power infrastructure of CTA must provide extra capacity of at least 10% beyond that needed by the baseline design. The power infrastructure must be flexible, adaptable and upgradable, with the possibility for additional instrumentation to be included (as well as adaptation to new technology).
- **B-INFRA-0605 Backup Power Control** : The Power Provision System must incorporate a backup solution, capable of continuously providing power to Array Elements for the average required loads.
- **B-INFRA-0610 Power Cable**: Telescopes and OES Controllable Systems must be provided with a cable power supply, which must be ducted in order to protect against damage to the cable between system and building, without impeding access to the System.
- **B-INFRA-0620 Power Interlocks**: There must be an interlock system which operates to prevent hazardous operations and to mitigate risk in case a hazardous situation arises.
- **B-INFRA-0630 Power Emergency Stop**: Emergency stop buttons to cut power, both to moving parts and to Array Elements as a whole, must be placed within all Interface Cabinets and in the data centre.
- **B-INFRA-0640 Power Frequency Stabilisation**: Voltage and frequency stabilisation must be considered in Power supply design, such that even on millisecond timescales, no disturbances may cause damage to Array Elements or the central system. For this purpose, an online UPS must exist.
- **B-INFRA-0650 Peak Power Load**: The installed electrical equipment (in the Power Provision System) must be able to carry the estimated peak power. The peak power for LST fast repositioning is excluded from this estimate and will be supplied by a dedicated storage system.
- **B-INFRA-0660 Peak Power Provision LST**: Extra power required by the LSTs, beyond the 60 KW to be provided by the Power Provision System, must be provided by the LST Energy Storage System.
- **B-INFRA-0670 Power System Availability (per Telescope)**: The availability of the power provision system at the telescope during observation time, including any back-up system, must be more than 99.5%
- **B-INFRA-0680 Power System Maintenance**: The maintenance of the power system on-site must require on average less than 10 person hours / week
- **B-INFRA-0690 Power System Grid Connection**: In the event that the connection of the power system to the grid is lost, the power system must be able to supply sufficient power for continued observations for up to 2 hours, and for the Safe State for up to 48 hours before the connection is restored.

2.3 Associated Requirements

In addition to those of the previous two sections, there are requirements associated to the power system and its functionality, yet applicable to other systems or generically to multiple systems.

All level B requirements are derived from higher level (A) requirements. For the power infrastructure, the most relevant level A requirement is: **A-OBS-1320 Power Infrastructure**: There must be sufficient power provided to enable regular operation of CTA. Additionally, a back-up power source must be provided, for a total overall power system availability of at least 99.5%

as well as several general requirements that lead to level B Infrastructure requirements listed below.

- **A-OBS 1300 Safety and Alarm system**: Elements relevant to human and instrument safety must be continuously monitored and controlled, with alarms generated as appropriate.
- **A-OBS 1310 Civil Infrastructure**: CTAO must provide all civil infrastructure necessary for the daily operation, with such infrastructure designed for cost-effective maintenance over the lifetime of the Observatory.
- **A-GEN-2102 Spare components**: A Spare Management System (SMS) must be put in place and make recommendations for a list of minimum spares and special tools which Observatory must keep on inventory. The SMS will also include an explanation of the technique to estimate parts and numbers required as well as other maintenance aspects.
- **A-GEN-2180 Safety regulations**: Construction, operation and decommissioning of the CTA systems must comply with European or host country regulations, whichever is more stringent, concerning health, human safety, as well as with the health and safety requirements described in sections 1, 3, 4 and 6 of Annex I of the directive 2006/42/EC on machinery.
- **A-GEN-2185 Environmental protection**: Construction, operation and decommissioning of the CTA systems must comply with applicable regulations on the protection of the environment.
- **A-GEN-2200 Design for error protection**: Systems must be designed for instrument safety at all times, including preventative measures for reasonably foreseeable errors.
- **A-GEN-2320 On site Operation Conditions**: Outdoor operations on site must be performed only during daytime and under safe weather conditions. No personnel will be available on-site during darktime observations. Instrumentation on-site must be designed such that manual intervention is not required during this time.
- **A-GEN-2350 Electrical safety**: Electrical installations, equipment and components must be provided with safety mechanisms and signalling to avoid any kind of human injury to personnel during installation, maintenance, regular use, inadvertent operation, human error or any kind of system failure.
- **A-GEN-2450 Electrical Elements**: Protection measures and devices must be used to guarantee that none of the observatory components and assemblies suffer permanent damage due to any reasonably foreseeable electrostatic discharge, power cut, electromagnetic disturbance or human error in cable connections.
- **A-GEN-2510 System lifetime**: The design lifetime of the system as a whole is 30 years, all individual assemblies must meet this requirement (see Lifetime) unless specified separately below.

A generic set of environmental requirements at level B is applicable to all systems deployed on the CTA sites, including the infrastructure [6]. The category “ONSITE” applies to all devices to be deployed at a CTA site. Relevant requirements concerning the connection of such devices to the power system include: **B-ONSITE-0100 Power Control**: It must be possible for the System power to be controlled both remotely via the SAS and by a person present at the System location.

All requirements will be kept up-to-date on the Jama system [8].

3 Appendices

3.1 Authors

Alison Mitchell (CTAO)
Jim Hinton (MPIK)
Carla Crovari (CTAO)

3.2 Power System Requirements Summary

Requirement ID	Title
B-xST-0610	Average Telescope Structure Power Consumption during Observations
B-xST-0640	Annual Average Telescope Structure Power Consumption in the Safe State
B-xST-0620	Peak Telescope Structure Power Consumption during Observations
B-xST-0630	Peak Telescope Structure Power Consumption in the Safe State
B-xST-1580	Average Camera Power Consumption during Observations
B-xST-1600	Annual Average Camera Power Consumption in the Safe State
B-xST-1570	Peak Camera Power Consumption during Observations
B-xST-1590	Peak Camera Power Consumption in the Safe State
B-INFRA-0500	Peak Power (South)
B-INFRA-0510	Power during observations (South)
B-INFRA-0520	Annual Energy Consumption (South)
B-INFRA-0530	Peak Power (North)
B-INFRA-0540	Power during observations (North)
B-INFRA-0550	Annual Energy Consumption (North)
B-INFRA-0580	Technical Building Power (South)
B-INFRA-0585	Technical Building Power (North)
B-INFRA-0590	Central Infrastructure Power (South)
B-INFRA-0595	Central Infrastructure Power (North)
B-INFRA-0505	Power Upgradability
B-INFRA-0560	Backup Power
B-INFRA-0570	Power Distribution
B-INFRA-0600	Power System Adaptability
B-INFRA-0605	Backup Power Control
B-INFRA-0610	Power Cable
B-INFRA-0620	Power Interlocks
B-INFRA-0630	Power Emergency Stop
B-INFRA-0640	Power Frequency Stabilisation
B-INFRA-0650	Peak Power Load
B-INFRA-0660	Peak Power Provision LST
B-INFRA-0670	Power System Availability (per Telescope)
B-INFRA-0680	Power System Maintenance
B-INFRA-0690	Power System Grid Connection

Table 3.1 – Summary of CTA Power Requirements. Requirements with an 'xST' ID are Telescope type specific, existing for each of LST, MST and SST.

3.3 Central Infrastructure Interface Requirements

Requirements on the Central CTA Infrastructure apply to all central Infrastructure, including the Central Infrastructure housing the Power System. Selected requirements that affect the interfaces of the Power

System to the Central Infrastructure are listed below as additional information. CTA must in all cases be compliant with the host country regulations. Note that in some cases the applicable standards are not yet fixed, especially for CTA-S, such that at the current time we adopt the standards specified in the IAC hosting agreement for CTA-N [9].

- **B-INFRA-0060 Interface Cabinet**: An Interface Cabinet must be provided at each Telescope to allow integration in to central infrastructure systems including: communications network; power network; and safety & alarm system. The cabinet must in addition support local maintenance work.
- **B-INFRA-0070 Interface Cabinet Electromagnetic Compatibility**: The Interface Cabinet must be electromagnetically compatible with the Telescope, with no measurable impact of noise generated by the Interface Cabinet on performace.
- **B-INFRA-0120 Parking and Storage Areas**: The CTA Observatory sites must have vehicle parking and outside storage areas largeenough to accommodate transport vehicles and shipping containers as needed to meet the needs of array construction and operation.
- **B-INFRA-0145 Access for Maintenance**: There must be sufficient pathways and access routes in place to ensure the safe access of personnel to any LRU for maintenance purposes.
- **B-INFRA-0200 Civil Infrastructure Extra Capacity**: The civil infrastructure of CTA, including on-site buildings must include additional capacity in the design, to provide later flexibility, wherever it is cost effective to do so.
- **B-INFRA-0250 Lightning Protection**: A grounding network connecting all buildings, Telescopes and other on-site hardware must be provided to enable an overall lightning protection level (LPL) of 1 to be reached.
- **B-INFRA-0260 Fire Safety**: All infrastructure supporting Telescopes and on-site hardware as well as buildings and access routes on site must be designed and constructed in compliance with the applicable fire safety regulations
- **B-INFRA-0270 Flood Damage Prevention**: Flooding of water courses and drainage must be such that the accumulation of the water cannot exceed 50 cm depth in any area with surface area larger than $10m^2$ that is not assigned as a drainage course/area.
- **B-INFRA-0280 Earthquake Damage Prevention**: All buildings and infrastructure supporting Telescopes and on site hardware must be designed and constructed to provide the appropriate level of protection against damage from Earthquakes.
- **B-INFRA-0330 Mechanical Workshop**: Both sites of the CTA Observatory must have appropriate mechanical workshop facilities for repair and testing (of LRUs) to meet the required availability and maintenance effort.
- **B-INFRA-0340 Electronics Laboratory**: Both sites of the CTA Observatory must have appropriate laboratory facilities for electronics assembly and testing within a clean environment, in order to meet the required availability and maintenance effort. Suitable levels of protection (e.g. electrostatic) must be provided.
- **B-INFRA-0350 Spare Part Storage Area**: Both sites of the CTA Observatory must have appropriate storage space to house the necessary stock of spare parts and materials in accordance with the Telescope and hardware maintenance plans.
- **B-INFRA-0360 Temporary Storage Area**: Both sites of the CTA Observatory must have sufficient additionally capacity to store elements on a temporary basis, e.g. prior to Telescope assembly, in accordance with the Telescope assembly plans.
- **B-INFRA-0370 Central Infrastructure Maintenance**: Both sites of the CTA Observatory must have sufficient equipment and storage space for spare parts to ensure the maintenance of all on-site infrastructure.

- **B-INFRA-0410 Light Pollution**: All buildings must be equipped with appropriate measures (including for example,shutters) to prevent light pollution at night time at above a level of 10^6 (d/100 m)^2 photons ns^{-1} sr^{-1} cm^{-2} on-site, where d is the distance to the nearest telescope.
- **B-INFRA-0470 Construction Vehicles**: During the construction and decommissioning phases, there must be sufficient vehicles available to support the construction and/or removal of Telescopes and hardware systems deployed on-site, in accordance with the assembly plans.
- **B-INFRA-0480 Maintenance Vehicles**: Both sites of the CTA Observatory must have sufficient vehicles available to facilitate the maintenance of Telescopes and hardware systems deployed on-site, in accordance with the Maintenance Plans.
- **B-INFRA-0490 Provision of Tools**: Both sites of the CTA Observatory must have sufficient tools available to facilitate the maintenance of Telescopes and hardware systems deployed on-site in accordance with the Maintenance Plans.
- **B-INFRA-1050 Electrical Safety**: All electrical installations, equipment and components must be regularly inspected and equipped with adequate safety mechanisms in compliance with the regulations of the host country.
- **B-INFRA-1210 Hazardous Areas**: Hazardous areas, or areas where damage to humans or critical components could result, must be properly signalled and access to them restricted to workers with adequate skills and certificates.
- **B-INFRA-1220 Skills and Certificates**: Operators of potentially hazardous equipment, as well as those in charge of abnormally dangerous activities, must be in possession of the appropriate skills and certificates.
- **B-INFRA-1380 SAS Power Control**: The SAS must be able to control the power supply to Telescope Structures and Cameras independently.

References

[1] CTA Consortium *Introducing the CTA Concept* Astroparticle Physics **43** 3-18 (2013)

[2] CTA Consortium *Science with the Cherenkov Telescope Array* arXiv:1709.07997 (2017)

[3] The Layouts of the CTA Arrays OBS-SCI/160420

[4] INFRA-DES-100-019 N P6

[5] CTAO GmbH *Study for Electrical Power Distribution North Array*, FICHT-18497028 (2018)

[6] Environmental Requirements for the CTA Sites SYS-REQ/161123

[7] CTA Illumination SYS-REQ/161018

[8] CTA Requirements `http://jama.cta-observatory.org/perspective.req`

[9] IAC-CTA Hosting Agreement, 09/09/2016