System Environmental Specification

020.10.15.10.00-0001-SPE

Status: **RELEASED**

PREPARED BY	ORGANIZATION	DATE
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Change Record

Version	Date	Author	Affected Section(s)	Reason
01	2017-10-02	R. Selina	All	Started first draft; used 020.25.00.00.00-0001-SPE-A as a template; pulling heavily from ALMA-80.05.02.00-001-B-SPE too
02	2017-10-12	R. Selina	1, 3, 4.	Incorporating suggestions from R. Treacy
03	2018-04-12	R. Selina	3.4	Clarified survival rain rate
04	2018-04-18	R. Selina	3.3	Clarified solar loads
04	2018-05-09	R. Selina	2, 3.4, 4.7	Updated survival rain rates
05	2018-05-11	R. Selina		Minor typos
06	2018-09-27	R. Selina	1.3, 3.1	Revised wind in Precision Environment to better reflect San Agustin Plains vs eastern NM used in initial analysis; updated introduction to match Ref. Design.
07	2018-10-02	R. Selina	3.1	Revised Normal Environment wind conditions to better reflect San Agustin Plains.
A	2019-07-09	A. Lear	All	Prepared document for review & approvals.
A.01	2019-08-01	R. Selina	3.1, 3.2, 3.3.	Updating for Requirements Review. Added RH and PWV specifications.
A.02	2020-04-23	A. Lear	All	Routed for review & revisions by PD.
B	2020-05-04	A. Lear	All	Prepared document for review & approvals.
B.01	2020-06-24	R. Selina	1, 2, 3, 4.2 4.8, 5	Updating to address RIDs from SRR. Added Standby Environment definition. Struck ENV0581, ENV0532. Added MIL-STD-810H standards for Vibration and Shock testing. Removed Section 1.3 to conform to new template.
B.02	2020-06-30	R. Selina	4.8	Revising drop test height for ENV0531.
B.03	2020-07-06	R. Selina	2.1, 3.5	Updated survival upper temperature bound. Corrected flow-down in Sect 2.
B.04	2020-07-08	R. Selina	4.8	Added new section for corrosion protection.
B.05	2020-08-04	R. Selina	3.6, 3.7	Added new transportation and storage environment definitions. Updated Radial Ice specifications.
B.06	2020-10-08	R. Selina	3.5, 3.6, 6.1	Final pass for SRR RID resolution. Added TK to cover sheet approvals.
B.07	2020-10-12	R. Selina, T. Kusel	3.6, 4.3	Clarifications to scope of transportation conditions and vibration requirements. Added missing requirements to verification table.
C	2020-10-13	A. Lear	All	Prepared PDF for approvals and release.

Table of Contents

1 Introduction

1.1 Purpose

This document aims to present the system-level environmental specification, incorporating a set of definitions and requirements. This specification is a subsection of the ngVLA System Requirements [AD01], which in turn flow down from the ngVLA Science Requirements and ngVLA Stakeholder Requirements.

The environmental specification has been broken out into a separate document for ease of reference, since the environmental definitions and requirements shall be incorporated into the requirement specifications of multiple subsystems.

1.2 Scope

The scope of this document is all buildings, infrastructure, and equipment that are located at the ngVLA site and exposed to the outside environment as part of regular operations. Equipment located within a regulated space (building, rack, etc.) shall establish their local operating conditions via an interface control document (ICD) with the respective subsystem providing the environmental control.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents are applicable to this Technical Specification to the extent specified. In the event of a conflict between the documents referenced herein and the content of this Requirements Specification, the content of the highest-level specification (in the requirements flow-down) shall be considered the superseding requirement for design elaboration and verification.

Ref. No.	Document Title	Rev/Doc. No.
AD01	ngVLA System Requirements	020.10.15.10.00-0003-REQ
AD02	International Standard: Protection Against Lightning	IEC 62305:2010
AD03	Department of Defense Test Method Standard: Environmental Engineering Considerations and Laboratory Tests	MIL-STD-810H

2.2 Reference Documents

The following references provide supporting context:

Ref. No.	Document Title	Rev/Doc. No.
RD01	USGS Coterminous US Seismic Hazard Map—PGA 2% in 50 Years	ftp://hazards.cr.usgs.gov/web/nshm/conterminous/2014/2014pga2pct.pdf
RD02	NOAA ATLAS 14 Point Precipitation Frequency Estimates: NM	https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nm

3 Definitions of External Environmental Conditions

Based on historical weather data of the VLA site and other public weather databases, the following definitions of environmental conditions are adopted.

3.1 Precision Operating Conditions

Parameter	Req. #	Value
Solar Thermal Load	ENV0311	Nighttime only; no solar thermal load within last 2 hours
Wind Speed	ENV0312	0 ≤ W ≤ 5 m/s average over 10 mins; 7 m/s peak gusts.
Temperature	ENV0313	–15 C ≤ T ≤ 25 C
Temperature Rate of Change	ENV0314	Up to 1.8°C/Hr
Precipitation	ENV0315	No precipitation
Precipitable Water Vapor	ENV0316	1–6 mm; 4 mm median

The precision operating environment defines the conditions under which the system is expected to meet the most stringent requirements and provide optimal system performance. The solar thermal load requirement limits this environment to two hours after sunset through sunrise, so long as the other requirements of this section are met. The two-hour restriction is intended to allow sufficient time for the system to thermally equilibrate.

3.2 Normal Operating Conditions

Parameter	Req. #	Value
Solar Thermal Load	ENV0321	Exposed to full sun, 1200W/m^2
Wind Speed	ENV0322	W ≤ 7 m/s average over 10 mins. 10 m/s peak gusts
Temperature	ENV0323	–15 C ≤ T ≤ 35 C
Temperature Rate of Change	ENV0324	Up to 3.6°C/Hr
Precipitation	ENV0325	No precipitation
Precipitable Water Vapor	ENV0326	1–26 mm; 18mm median

When the environment meets the constraints of the normal operating conditions, system performance requirements are relaxed but are still expected to provide adequate performance for operation below 50 GHz. The relevant performance specifications are discussed in [AD01].

3.3 Limits to the Operating Conditions

Parameter	Req. #	Value
Solar Thermal Load	ENV0330	Exposed to full sun, 1200W/m^2
Wind	ENV0331	W ≤15 m/s average over 10 mins; W ≤20 m/s gusts
Temperature	ENV0332	–20 C ≤ T ≤ 45 C
Precipitation	ENV0333	Up to 5 cm/hr over 10 mins
Ice	ENV0334	Equivalent to radial ice of 2.5 mm
Relative Humidity	ENV0335	0 ≤ RH ≤ 100%; condensation permitted

A third categorization will establish hard limits to the operating conditions. While outside the bounds of the normal operating environment but within this regime, no performance guarantees are expected, but the system shall still be capable of safe operation.

3.4 Standby Conditions

Parameter	Req. #	Value
Solar Thermal Load	ENV0360	Exposed to full sun, 1200W/m^2
Wind	ENV0361	0 m/s ≤ W ≤ 30 m/s average
Temperature	ENV0362	–25 C ≤ T ≤ 45 C
Precipitation	ENV0363	Up to 5 cm/hr over 10 mins
Ice	ENV0364	Equivalent to radial ice of 2.5 mm
Relative Humidity	ENV0365	0 ≤ RH ≤ 100%; condensation permitted
Standby Recovery Time	ENV0366	The system shall resume operation to specification within 5 minutes of conditions returning to the constraints of the Normal or Precision Operating Conditions.

After the limit to the operating conditions are exceeded, the antennas will be placed in the "stow-survival" position for equipment safety and the system placed in a standby state. While in standby, the system shall remain capable of resuming operation within five minutes of conditions returning to within the Limits of the Operating Conditions. Should the environment then reach the Normal Operating Conditions, the system shall perform to the performance specifications associated with that environment.

Subsystems may automatically shut down, or have temporarily degraded performance, once the environment exceeds the constraints of the Standby Conditions.

3.5 Survival Conditions

Parameter	Req. #	Value
Wind	ENV0341	0 m/s ≤ W ≤ 50 m/s average
Temperature	ENV0342	–30 C ≤ T ≤ 50 C
Radial Ice	ENV0343	2.5 cm
Rain Rate	ENV0344	16 cm/hr over 10 mins
Snow Load, Antenna	ENV0345	25 cm
Snow Load, Equipment & Buildings	ENV0346	100 kg/m^2 on horizontal surfaces
Hail Stones	ENV0347	2.0 cm
Antenna Orientation	ENV0348	Stow-survival, as defined by antenna designer

The survival conditions describe the environment that the antenna and all outside structures should be able to withstand without damage when placed in its least-vulnerable state. The antenna designer will specify the antenna elevation that will result in minimum stress to the structure at the maximum wind speed and maximum snow and ice loading. Note that this position shall be static (i.e. a single stow-survival position, not dynamic in azimuth or elevation.) Subsystems housed within or on the antenna shall assume this orientation.

The temperature limits, radial ice, snow load, and hail stone requirements are based on experience at the VLA site and a survey of conditions throughout the extent of the array.

3.6 Transportation Conditions

Parameter	Req. #	Value
Solar Thermal Load	ENV0381	Exposed to full sun, 1200W/m^2
Transportation Temperature	ENV0382	–30 C ≤ T ≤ 60 C

The transportation environmental conditions are applicable during the operations phase of the lifecycle, for line replaceable units and service components that will be transported to and from the antenna or other ngVLA service facilities. These components can be assumed to be in a powered-off state and packaged for transportation.

Line Replaceable Units (LRUs) and other service components, supplies and tools would either be:

- Secured in the back of an open-bed truck, using any required and provided packaging or transportation enclosures for their protection, or
- Secured within an enclosed service van, truck or SUV, using any required and provided packaging or transportation enclosures.

The transportation environmental conditions should be considered an extension of the survival conditions, differing in the key respect of temperature—reflecting that equipment may be located in an enclosed vehicle during the heat of the day.

Other requirements applicable to transportation, such as allowable mechanical shocks and vibrations, are defined in Section 4.

3.7 Storage Conditions

Parameter	Req. #	Value
Storage Temperature	ENV0372	0 C ≤ T ≤ 30 C
Storage Relative Humidity	ENV0373	10 ≤ RH ≤ 90%

These storage condition definitions are provided to support a reliability analysis. During the operations phase of the system lifecycle, spare parts and equipment will be stored in a warehouse environment. The environment is assumed to be passively regulated for temperature and humidity.

3.8 Site Elevation

Parameter	Req. #	Value
Altitude Range	ENV0351	All system elements shall be designed for operation and survival at altitudes ranging from sea level to 2500 m.

The chosen design elevation accommodates the antennas on the Plains of San Agustin and the identified main array sites. Some candidate long baseline sites may exceed this elevation, and any design modifications will be considered on a case-by-case basis.

4 Environmental Protection Requirements

4.1 Lightning

Parameter	Req. #	Value
Lightning Protection, Structure	ENV0511	The antenna, buildings, and housed equipment shall be protected from both direct and nearby lightning strikes, achieving Protection Level 1 as defined in IEC 62305-1/3. [AD02]
Lightning Protection, Electronics Systems	ENV0512	The building and antenna electrical and electronics systems shall be protected against Lightning Electromagnetic Impulse (LEMP) in accordance with IEC 62305-4. [AD02]
Lightning Protection, Personnel	ENV0513	A safety hazard analysis shall be performed for anticipated preventive maintenance tasks that may place personnel at risk in the event of direct or nearby lightning strikes.

Given the extent of the array and the prevailing environmental conditions, direct and nearby lightning strikes, causing a lightning electromagnetic pulse (LEMP), should be anticipated and mitigated in the antenna design. The antenna and housed equipment shall be protected in any antenna orientation. All antenna bearings shall have bypass grounding connections. Grounding systems shall be designed to minimize ground loops. Multi-point grounding is a necessity imposed by the need for Radio Frequency Interference (RFI) shielding, but the effects should be minimized in signal paths wherever possible.

The lightning protection system shall be designed to achieve Protection Level I as defined by IEC 62305-1—Protection Against Lightning [AD02]. This level assures protection against 99% of strikes, with a residual risk of damage for strikes with parameters outside the defined range.

4.2 Seismic

Parameter	Req. #	Value
Seismic Protection	ENV0521	The system shall be designed to withstand a low-probability earthquake with up to 0.2g peak acceleration in either the vertical or horizontal axis.

Low probability has been defined as a 2% probability of an event exceeding this magnitude over a 50-year period, consistent with data available from the USGS Seismic Hazard Model [RD01]. Equipment shall be designed to survive this standard in any operational condition and orientation.

4.3 Vibration

Parameter	Req. #	Value
General Vibration	ENV0531	All LRUs packaged for transportation, and any equipment installed in the antenna, shall be designed to withstand persistent vibration with a power spectral density defined in Figure 1. Line Replaceable Units shall be tested to this vibration specification along all three axes as defined in the MIL-STD-810H Method 514.8 Procedure I for General Vibration, for a period of 60 minutes.

The vibration mitigation requirement is especially applicable to all mechanical connectors. All cables shall be mechanically supported to mitigate vibration loosening of connectors.

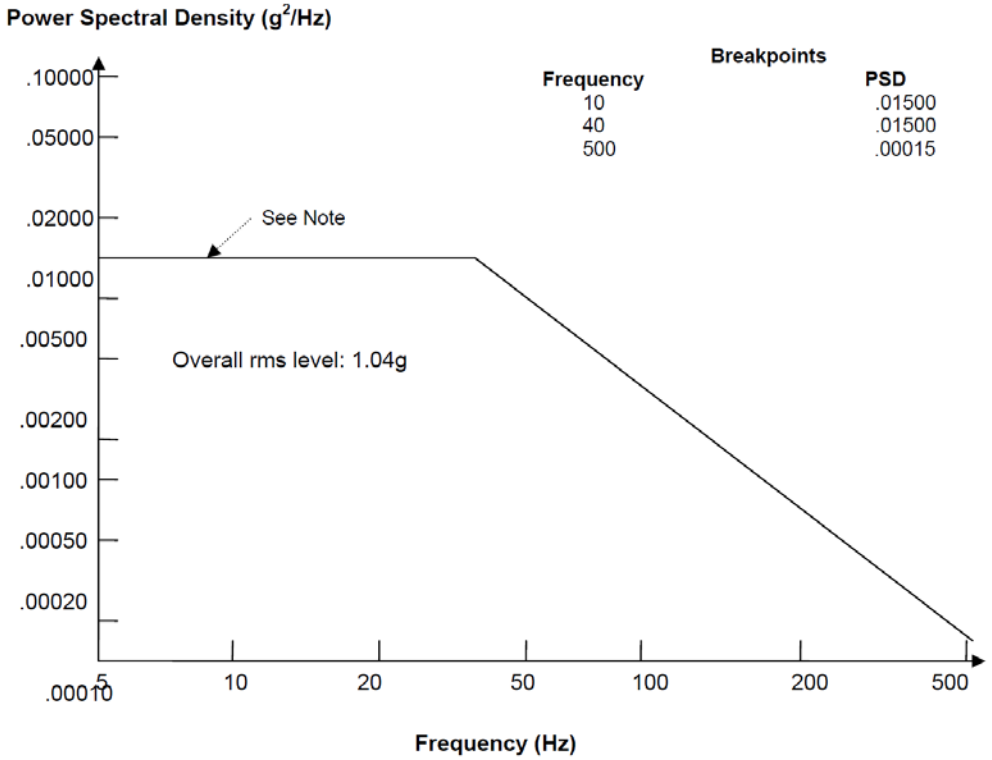

Figure 1 – Power spectral density of design spectra for vibration mitigation. Adopted from ALMA-80.05.02.00-001-B-SPE.

4.4 Dust

Parameter	Req. #	Value
Equipment Protection	ENV0541	Exposed equipment shall be protected against windblown dust, ashes, and grit.
Building Protection	ENV0542	Building envelopes shall be tight enough to mitigate penetration of dust. All air circulation penetrations shall be filtered.

4.5 Fauna

Parameter	Req. #	Value
Rodent Protection	ENV0551	Exposed equipment shall be designed to prevent rodent damage. At a minimum this may involve protecting all cables with flexible or rigid conduit or equivalent. Any penetration within enclosures and raceways shall mitigate the risk of rodent damage.
Large Mammal Protection	ENV0552	Exposed equipment shall be protected against damage by large mammals such as cattle.

Note that the large mammal protection requirement needn't be met by all exposed equipment directly. For example, if a fence is provided around each antenna, equipment within the fence envelope can be built assuming that the fence provides adequate large mammal protection.

4.6 Solar Radiation

Parameter	Req. #	Value
Maximum Solar Flux	ENV0561	All equipment exposed to outside environment shall be designed for a maximum diurnal solar flux of 1200 W/m² from 0.3–60 μm.
Maximum UV Radiation	ENV0562	All equipment exposed to outside environment shall be designed for a maximum diurnal UV radiated flux of 100 W/m² from 280–400 nm.

4.7 Rain/Water Infiltration

Parameter	Req. #	Value
Rain/Water Infiltration	ENV0571	Exposed equipment enclosures shall be designed to withstand rainfall intensity up to 16 cm/hr., with droplets sized 0.5 to 4.5mm, at a wind velocity of 15 m/s from the vertical to horizontal direction.

The survival rain rates correspond to 50-year events as defined in [RD02].

4.8 Corrosion Protection

Parameter	Req. #	Value
Corrosion Protection	ENV0591	Exposed equipment shall be designed to prevent corrosion that may impact the performance or structural integrity of the equipment over the system design life (see SYS2801).

4.9 Mechanical Shock

Parameter	Req. #	Value
Mechanical Shocks	ENV0582	Line Replaceable Units packaged for transportation shall survive mechanical shock levels from handling as defined in the MIL-STD-810H Method 516.8 Logistic Transit Drop Test, modified to use the drop heights specified in Table 1.

Mass of Package	Height of Drop	Number of Drops
0 kg to 25 kg	75 cm	Drop on each face and corner. Total of 26 drops.
25 kg to 50 kg	75 cm	Drop on each corner. Total of 8 drops.
50 kg to 100 kg	35 cm	Drop on each bottom edge and bottom face. Total of 5 drops.
> 100 kg	25 cm	Drop on each bottom edge and bottom face. Total of 5 drops.

Table 1 – Modified drop heights for logistic transit drop test.

5 Verification

The design may be verified to meet the requirements by analysis (A), inspection (I), a demonstration (D), or a test (T), each defined below.

Verification by Analysis: The fulfillment of the specified performance shall be demonstrated by appropriate analysis (hand calculations, finite element analysis, thermal modeling, etc.), which will be checked by the ngVLA project office during the design phase.

Verification by Inspection: The compliance of the developed system is determined by a simple inspection or measurement.

Verification by Demonstration: The compliance of the developed feature is determined by a demonstration.

Verification by Test: The compliance of the developed system with the specified performance shall be demonstrated by a documented acceptance test.

Multiple verification methods are expected over the course of the design, providing evidence of design compliance at key review milestones. The primary (final) verification method at the system-level is identified below. Subsystems or individual components may have alternate methods of verification, depending on the risk presented by the given parameter to that subsystem or component. E.g., while the Maximum UV Radiation (ENV0562) may be verified by inspection at the system level, this does not preclude requiring accelerated aging tests for UV exposure for the feed windows (verification by test).

Req. #	Parameter/Requirement	A	I	D	T
ENV0311	Precision: Solar Thermal Load	*			
ENV0312	Precision: Wind Speed	*			
ENV0313	Precision: Temperature	*			
ENV0314	Precision: Temperature Rate of Change	*			
ENV0315	Precision: Precipitation		*		
ENV0316	Precision: Precipitable Water Vapor	*			
ENV0321	Normal: Solar Thermal Load	*			
ENV0322	Normal: Wind Speed	*			
ENV0323	Normal: Temperature	*			
ENV0324	Normal: Temperature Rate of Change	*			
ENV0325	Normal: Precipitation		*		
ENV0326	Normal: Precipitable Water Vapor	*			
ENV0330	Limit: Solar Thermal Load	*			
ENV0331	Limit: Wind Speed	*			
ENV0332	Limit: Temperature	*			**(I)**
ENV0333	Limit: Precipitation		*		
ENV0334	Limit: Ice	*			
ENV0335	Limit: Relative Humidity		*		
ENV0360	Standby: Solar Thermal Load	*			
ENV0361	Standby: Wind		*		
ENV0362	Standby: Temperature	*			
ENV0363	Standby: Precipitation		*		
ENV0364	Standby: Ice		*		
ENV0365	Standby: Relative Humidity		*		
ENV0366	Standby Recovery Time	*			

Req. #	Parameter/Requirement	A	I	D	T
ENV0341	Survival: Wind	*			
ENV0342	Survival: Temperature	*			
ENV0343	Survival: Radial Ice	*			
ENV0344	Survival: Rain Rate				*
ENV0345	Survival: Snow Load, Antenna	*			
ENV0346	Survival: Snow Load, Equipment & Bldgs.	*			
ENV0347	Survival: Hail Stones				*
ENV0348	Survival: Antenna Orientation		*		
ENV0381	Solar Thermal Load	*			
ENV0382	Transportation Temperature	*			**(2)**
ENV0351	Altitude Range	*			
ENV0511	Lightning Protection, Structure		*		
ENV0512	Lightning Protection, Electronics Systems		*		
ENV0513	Lightning Protection, Personnel	*			
ENV0521	Seismic Protection	*			
ENV0531	General Vibration				*
ENV0541	Equipment Protection		*		
ENV0542	Building Protection		*		
ENV0551	Rodent Protection		*		
ENV0552	Large Mammal Protection		*		
ENV0561	Maximum Solar Flux		*		
ENV0562	Maximum UV Radiation		*		
ENV0571	Rain/Water Infiltration				*
ENV0582	Mechanical Shocks				*
ENV0591	Corrosion Protection		*		

(1) Components exposed to Limit conditions during operations shall be tested for safe operation and for not incurring residual damage. Test profiles shall include:

- Start-up sequence from off to operational at minimum temperature (at least 20 cycles).
- Extended operation (60 minutes) at maximum operating temperature.
- Maximum rate of change of temperature (up and down) between minimum and maximum values (at least 20 cycles).

(2) All LRUs that are transported shall be tested for not incurring residual damage at maximum transportation temperature over an extended period (at least 4 hours).

6 Appendix

6.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
ALMA	Atacama Large Millimeter/Sub-Millimeter Array
CFD	Computational Fluid Dynamics
HVAC	Heating, Ventilation & Air Conditioning
ICD	Interface Control Document
IEC	International Electrotechnical Commission
IPT	Integrated Product Lead
LEMP	Lightning Electromagnetic Pulse
LRU	Line Replaceable Unit
ngVLA	Next Generation VLA
NRAO	National Radio Astronomy Observatory
PI	Principal Investigator
RD	Reference Document
RFI	Radio Frequency Interference
RH	Relative Humidity
SAC	Science Advisory Council
SUV	Sport Utility Vehicle
TAC	Technical Advisory Council
TBD	To Be Determined
USGS	United States Geological Survey
UV	Ultraviolet
VLA	Jansky Very Large Array