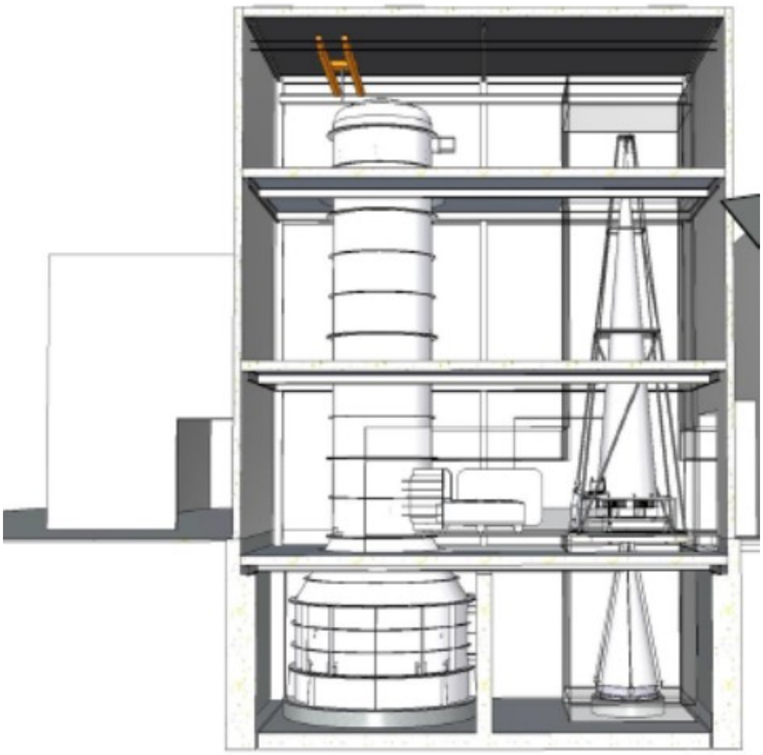
VERT-X Design of Vertical X-Ray Test Facility for ATHENA

TN13 REQUIREMENTS COMPLIANCE MATRIX

Doc: VTX-OAB-IPA-TEC-001

Date: 17 / 04 / 2020



CHANGE RECORDS						
ISSUE	**DATE**	**AUTHOR**	**APPROVED**	**QA/QC**	**SECTION / PARAGRAPH AFFECTED**	**REASON/INITIATION Documents/Remarks**
I01p00	10/01/2020				All	First Issue
I01p01	17/04/2020				Section 3	R04+Minor modifications

AUTHORS AND RESPONSIBLES			
Document:	VTX-OAB-IPA-TEC-001		
Issue:	I01p01		
Date:	17/04/2020		
Prepared by:	Alberto Moretti (INAF - OAB)	Signed by:	
	Massimiliano Tordi (EIE)		
	Fabio Marioni (MLS)		
	Giancarlo Parodi (BCV)		
	Franco Amisano (GPAP)		
Checked by:	Alberto Moretti (INAF - OAB)	Signed by:	
Approved by:	Stefano Basso (INAF - OAB)	Signed by:	
Released by:	Alberto Moretti (INAF - OAB)	Signed by:	

CONTRIBUTING ENTITIES	
INAF – OAB	Partner
INAF - IASF	Partner
Media Lario	Partner
EIE	Partner
GP Advanced Projects	Partner
BCV	External Service

TABLE OF CONTENTS

1. INTRODUCTION 5
1.1. SCOPE 5
1.2. APPLICABILITY 5
1.3. ROADMAP 5
2. APPLICABLE AND REFERENCE DOCUMENTS 6
2.1. APPLICABLE DOCUMENTS 6
2.2. REFERENCE DOCUMENTS 6
2.3. GENERAL SPECIFICATIONS AND STANDARD DOCUMENTS 6
2.4. LIST OF ACRONYMS 8
3. COMPLIANCE TO STUDY REQUIREMENTS 9

LIST OF TABLES

Table 1-1: Roadmap of the document 5
Table 3-1: VERT-X requirements compliance matrix........ 9

1. INTRODUCTION

1.1. SCOPE

The scope of the present document is the illustration of VERT-X requirements compliance matrix, following the outcomes of the System Requirements Review (SRR) and of the Preliminary Design Review (PDR).

1.2. APPLICABILITY

The present document is one of the deliverables related to the PDR milestone outcomes. It is intended to be an input to VERT-X preliminary design and a driver for the requirements compliance verification in the study.

1.3. ROADMAP

Document section	Content description
Section 2 (Applicable and reference documents)	List of applicable documents and reference documents.
Section **Error! Reference source not found.** (Compliance to study requirements)	Review of VERT-X design compliance to study requirements.

Table 1-1: Roadmap of the document

2. APPLICABLE AND REFERENCE DOCUMENTS

2.1. APPLICABLE DOCUMENTS

AD1	AO/1-9549/18/NL/AR - SOW	X-ray Raster Scan Facility for the ATHENA Mirror Assembly SOW
AD2	VERT-INAFOAB-001	VERTICAL X-Ray (VERT-X) Technical Proposal
AD3	ESA-TECMMO-RS-014713	Updated Requirements for the ATHENA VERT-X following the System Requirements Review
AD4	ESA-ATHENA-ESTEC-SCI-PL-0001	Optics Calibration Plan
AD5	ESA-ATH-SP-2016-001	Calibration Requirements Document,
AD6	ESA- ATHENA-ESTEC-SYS-RS-0003	Mirror Calibration Facility URD

2.2. REFERENCE DOCUMENTS

RD1	VTX-EIE-ISE-TEC-001	TN1 Vacuum Chamber
RD2	VTX-MLS-ISE-TEC-001	TN2 X-ray Source and Collimator System
RD3	VTX-EIE-ISE-TEC-002	TN3 Raster Scan System
RD4	VTX-EIE-ISE-TEC-003	TN4 MA mechanical support and thermal system
RD5	VTX-OAB-ISE-TEC-002	TN5 X-ray detector and (x, y, z) stage
RD6	VTX-OAB-ISE-TEC-003	TN6 Gravity Release Structure/Mechanism
RD7	VTX-EIE-ISE-TEC-004	TN7 Metrology System
RD8	VTX-EIE-ISE-TEC-005	TN8 Ground Segment Equipment
RD10	VTX-EIE-IFF-SPC-001	TN10 Interface Specifications
RD11	VTX-OAB-IOP-TEC-001	TN11 Concept of Operation
RD12	VTX-OAB-ISE-TEC-001	TN12 Technical Budgets
RD13	VTX-OAB-ISE-REP-003	D4 Preliminary design document
RD14	VTX-OAB-ISE-REP-001	Conceptual Design Report
RD15	VTX-OAB-ISE-REP-002	Trade-off Report

2.3. GENERAL SPECIFICATIONS AND STANDARD DOCUMENTS

SD1	ECSS-M-40A	Configuration management

SD2	ECSS-M-50A	Information/documentation management

2.4. LIST OF ACRONYMS

AD	Applicable Document
AIT	Assembly, Integration and Testing
C	Compliant
DD	Detailed Design
ESA	European Space Agency
GPAP	GP Advanced Projects
I/F	Interface
IASF	Istituto di AstroFisica Spaziale (INAF, Milano)
IDP	Documentation Delivery Packages
INAF	Istituto Nazionale di AstroFisica
ITT	Invitation To Tender
MA	Mirror Assembly
MLS	Media Lario S.r.l.
MM	Mirror Module
PC	Partially Compliant
PD	Preliminary Design
PDR	Preliminary Design Review
RD	Reference Document
SIM	Science Instrument Module
SOW	Statement of Work
SRR	System Requirements Review
TBA	To Be Assessed
TBC	To Be Controlled
TVC	Thermal vacuum chamber
VERT-X	VERTICAL X-Ray
VTX	VERT-X
XRD	X-Ray Detector
XRS	X-Ray Raster Scanner
XYZS	(x, y, z) stage

3. COMPLIANCE TO STUDY REQUIREMENTS

Req. ID	Requirement definition (with post-SRR updates)		NOTES
R01	The XRS Facility shall allow the functional and performance verification of the partially or fully integrated ATHENA MA, as well as its final calibration, by scanning the MA with a vertical small-aperture highly-collimated and actively controlled X- ray beam and collecting the output beam at the focal plane of the MA.	**C**	In the VERT-X preliminary design the low-divergence X-ray beam (~1"), needed for verification and calibration, is produced placing a source in the focus of an X-ray collimator. This system is mounted on a raster-scan mechanism which covers the entire ATHENA optics (**RD13**). This facility will allow the MA verification and calibration tests in compliance with verification and ground calibration plans (**AD4**, **AD5, AD6**).
R02	The XRS Facility shall be able to perform any manipulation of the MA, inside the vacuum chamber, required to satisfy the verification and calibration requirements, without breaking the vacuum. Note: this requirement is schedule-derived, alternative approaches can be proposed if compliance with schedule requirements.	**C**	All the components installed within the chamber are compliant with operations in vacuum and they will be remotely controlled. No manipulation of the MA is foreseen during the verification and calibration operations (**RD1-RD13**).
R03	The XRS Facility shall be able to routinely perform beam-characterization measurements (direct beam on detector) while the MA is in the chamber under vacuum.	**C**	The detector stage is designed to directly expose the detector to the X-ray beam. This will be through the MA central aperture or at the MA edge (**RD5).** Direct beam measures are functional to the purposes of the EA calibration (**RD11**).
R04	The XRS Facility shall provide the possibility to arbitrarily isolate the Point Spread Function (PSF) of each MM.	**C**	Raster scan mechanism has the capability of moving the parallelized beam in order to illuminate each single module. This is provided by scaling-down, the beam footprint by means of a mask. A reduction of 80% of the beam size allows the characterization of each single module.
R05	The scanning speed of the XRS shall be defined following a trade-off between requirement R25 and R50.	**C**	Raster scan can be moved with the required pointing accuracy up to ~ 30 mm/s (**RD3**). As discussed in **RD11**, maximum speed is not necessary for the large part of the calibration and verification tests. This is because the duration of the PSF and EA calibration measures will be determined by the detector pile-up limit.
R06	The absolute knowledge error of the HEW for the verification and calibration of the MA and for different energies used and off-axis angles shall be ≤ 1 arcsec (goal: 0.5 arcsec) with a confidence level of 99.73% (3σ).	**C**	The VERT-X measure of HEW is the result of the (quadratic) sum of HEW_{MA} with several independent contributions: the pointing uncertainty, the source dimension, the mirror error and the gravity induced distortions. As discussed in **RD11,** the estimated uncertainty on the HEW is ~ 0.1" (1 sigma), also accounting for the statistical error.
R07	The maximum effective area loss introduced during verification and calibration of the MA for different energies and off-axis angles shall be ≤ 1%, with a confidence level of 99.73% (3σ).	**C**	In conical approximation design, the loss of effective area (EA_{loss}) due to geometrical vignetting of a divergent beam is given by EA_{loss} = 2 theta/alpha; where alpha is the parallel incident angle for a parallel beam and theta is the beam divergence. Since the minimum alpha for ATHENA MA is 0.3° a 1% vignetting factor would be given by a divergence of ~6.0", as minimum. This is much larger than the designed beam divergence.

Req. ID	Requirement definition (with post-SRR updates)		NOTES
R08	The absolute knowledge error of the effective area loss introduced during verification and calibration of the MA for different energies and off-axis angles shall be ≤ 1%, with a confidence level of 99.73% (3σ).	**C**	The expected beam divergence is discussed in RD12, in the HEW error budget Section. Using the design value and the formula linking EA_{loss} to beam divergence we find that value of EA_{loss} and its uncertainty are well below 1%.
R10	The closed-loop control system shall feedback information in order to keep X-ray beam, MA and detector in the required alignment and to consequently allow the automatic tip-tilt adjustment of the collimated X-ray beam (ref. to requirement R30 and R32).	**C**	The measurement of the relative displacement between the MA and the XRD, are performed by the linear displacement metrology. The orientation of the X-ray beam with respect to a given reference is determined by the tip-tilt metrology. The orientation of the MA and the XRD is measured against the gravity, by using tilt-meters (**RD3**, **RD7**).
R11	The vacuum chamber shall be designed in a way to contain and structurally support the following three systems, preferably arranged in a vertical configuration as depicted in SOW Figure 1, and in sequence as per the following:		In the PD the TVC, is a 20 m tall and 4 to 7 m wide cylindrical vertical vessel subjected external pressure. It houses the X-Ray Raster Scan, the Mirror Assembly, and the Detector (**RD1**).
	- The X-ray source and collimator system, together with the raster scan system (all to be designed/procured);	**C**	
	- The MA (provided by SC-Prime - physical characteristics and interfaces as per SOW [AD1];	**C**	
	- The detector (to be designed /procured) or the SIM (provided by SC-Prime - physical characteristics and interfaces as per SOW [RD7] - [RD9]).	**C**	
R12	The vacuum chamber shall allow the insertion and removal of the fully assembled MA and detector stage (note: top end of the vacuum chamber shall be designed to be removable if needed, e.g. via a flange).	**C**	One large door at the Mirror Assembly level (clear aperture 3.2 m x 1.6 m), for MA insertion/extraction is included in the design (**RD1**). One opening at the top of the vessel, corresponding to the top end of the chamber (clear aperture Ø 4 m), for detector insertion/extraction is also designed (**RD1**).
R13	The vacuum chamber shall offer at least an ISO 5 environment in presence of the MA without protective cover.	**C**	Both the MA and the detector openings are connected to ISO 5 clean rooms in such a way that when the vessel is open, it remains at an environmental cleanliness level corresponding to ISO 5 (**RD1**).
R14	The vacuum chamber shall offer openings that allow the entrance of operators and GSE as required to perform all the operations necessary to run and maintain the XRS Facility for the execution of the performance verification campaigns for the Qualification Model (QM) and Flight Model (FM) MA and calibration campaign for the FM MA.	**C**	One small doors at the -1 (Raster Scan) level (clear aperture 1.7 m x 1.2 m), for personnel access and small pieces insertion/extraction (**RD1**).
R15	The vacuum chamber shall be equipped with a vacuum generation system to create an internal pressure down to 10^{-6} Torr and in a time compatible with the foreseen operations necessary to execute the performance verification and calibration campaigns for the QM/FM MA, as per SOW [AD1] (<LBF-URD> tab of the annexed excel file), SOW [RD4] and [RD5]. Goal: pressurization time should be less than 5 hours.	**C**	The general configuration of the vacuum generator system consists of three different subsystems. (i) primary vacuum until 1e-2 mbar: 3 dry pumping groups (~2200m3/h) in parallel with ISO 160 valves and ISO 160 tubes; (ii) secondary vacuum until 1e-3 mbar: 2 turbomolecular pumps (4000l/s) with ISO 320 valves, a primary vacuum line with a unique dry pumping; (iii) high vacuum until 1e-6 mbar 2 cryogenic pumps (8000, 10000, 12000 l/s for N2, 18200, 30000, 28550 l/s for water respectively) with ISO 400 & 500 valves, a primary vacuum line with a unique dry pumping (**RD1**).

Req. ID	Requirement definition (with post-SRR updates)		NOTES
R16	The vacuum chamber shall be equipped with a thermal control system to keep the MA temperature at 20°C ±1°C. Note: The MA will use its own thermal control system, consisting of heaters, but a lower sink temperature on the facility is needed.	**C**	To keep the MA in the requested thermal conditions, a thermal shroud assembly has been designed in a sandwich configuration to allow the MA going in and out the TVC (**RD1**).
R17	The vacuum chamber should offer suitable windows in correspondence of the collimator, MA and detector/SIM to allow optical metrology to sense inside the vacuum chamber.	**C**	A preliminary layout of the main viewports for the optical metrology has been defined. The layout will be updated in the Detailed Design. They will be integrated in a further development step being related to the main elements location confirmation (namely the metrology and vacuum generation system).
R18	The vacuum chamber shall be equipped with interface flanges to allow power and data cables connection between internal and external GSE during operational (vacuum) and non-operational conditions.	**C**	Interfaces flanges and feedthroughs will be included in the DD. They will be integrated in a further development step being related to the main elements final location (metrology, vacuum generation).
R19	The X-ray source and collimator system shall be compatible with operations in high vacuum conditions (as per requirement R15).	**C**	The baseline X-ray source is Sigray FAAST, which can be operated in vacuum and moved by the raster-scan mechanism. It is described in **RD2**.
R20	A set of X-ray sources shall be selected to perform the required performance verifications and calibration campaigns of the MA at 7 energies: C-K, Al-K, Ag-L, Ti-K, Fe-K, Cu-K, Ge-K.	**C**	The baseline X-ray source can be equipped with four different targets. In **RD11** we discuss the possibility of accomplishing the verification and calibration task using the continuum spectrum and exploiting the detector energy resolution.
R21	The selected set of X-ray sources shall be integrated in a system that can automatically change the X-ray source to be operated and without breaking vacuum.	**C**	This is included in the baseline X-ray source capabilities (**RD2**).
R22	The X-rays emitted by the source shall be collimated in a beam having the largest cross-section possible.	**C**	The size of the collimated beam is presented in **RD2**. It consists in a portion of a circular corona with 60 and 64 cm of internal and external radius respectively for a total are of 258 mm^2 .
R24	The collimated X-ray beam shall be directed to the plane of the MA, i.e. in the *z* direction (with reference to the coordinate system).	**C**	By design of the tube which hosts the X-ray source and the collimator and which is moved by the raster-scan mechanism (**RD3**).
R25	Sufficient X-ray flux shall be generated to characterize the local PSFs of the MA, without being significantly affected by statistical uncertainties.	**C**	The statistical uncertainties in the HEW and PSF calibration as function of the number of collected photons are discussed in **RD11**. The statistical error is one of the terms of the HEW error budget.
R27	The absolute knowledge error of the flux during the scan of the whole MA shall be ≤ 3%, with a confidence level of 99.73% (3σ). Note: this requirement drives a) the need to perform direct beam measurements with enough range on the detector to cover the whole aperture, and b) the sensitivity of the detector.	**C**	According to the planned operations (**RD11**) a fraction of the exposure time used for EA calibration will be devoted to direct measure of the beam. Cadence of these measures will be such that X-ray source expected variations will be well below 1%. X-ray flux will be also monitored by a detector positioned at ~ 20 cm from the source.
R29	The X-ray source and collimator system shall be mounted on a *(x, y)* translation stage (with reference to the coordinate system), which shall be compatible with operations in high vacuum conditions (as per requirement R15).	**C**	Raster-scan mechanism design is reported in **RD3.** This is fully compatible with high vacuum operations.
R30	The positioning of the X-ray beam (i.e. the X-ray collimator) shall be controlled by an external metrology system.	**PC**	The zero of the position can be determined by the metrology. The position relative to the zero is obtained from the linear encoders of the motion system (**RD3**).

Req. ID	Requirement definition (with post-SRR updates)		NOTES
R31	It shall be possible to tip-tilt the direction of the collimated X-ray beam in a range of ±3° around the z-axis (as per reference system of Figure 1). A maximum absolute knowledge error of 0.2 arcsec shall be achieved with a confidence level of 99.73% (3σ) for off-axis angles up to 20 arcmin during scanning. Note: This is in principle a derived requirement. It is not necessary to have a very good static accuracy on the set point, but it is important to have a good relative knowledge during scanning. This can be achieved by either having a very dynamically stable system or by having a good metrology (to be able to accurately track the angle for a faithful reconstruction of the PSF during data processing).	PC	**RD7** describes the tip/tilt servo model which has been created to prove the capability of the envisaged system (control, plus mechanism, plus structure) to effectively move and control the X-ray beam attitude. The reported position errors of the tube attitude measured at the encoders are 0.16" and 0.06" (RMS) for ROT-X and -Y respectively. We note that this requirement only concerns one term of the entire HEW error budget, which is made up by several terms (**RD11).** As **Req. 31** is derived and functional to the **Req. 6**, the resulting error budget allocation is slightly different from the one derived from the requirements, and it is fully compliant with **Req. 6**, which is the parent one.
R32	The tip/tilt of the X-ray beam shall be controlled rapidly enough to maintain the require alignment - verticalization of the beam with the MA and the detector in a dynamical way during the raster scanning.	C	The Raster Scan tip / tilt control system consist of (i) an inner loop — based on the encoder signal — that controls tube angular position by chasing the set point; (ii) an outer loop — based on tip / tilt metrology — that fixes the tube attitude by correcting the set point of the inner loop. Performance of the control system on the X-ray beam attitude has been assessed by servo analysis (**RD3, RD7**).
R34	The XRS Facility shall offer suitable mechanical interfaces to sustain the MA, in compliance with SOW [AD1], and preferably with the MA optical axis in vertical direction, i.e. in the z direction (with reference to the coordinate system.	C	The gravity mitigation consists in a supporting system contrasting axial gravity effects, limiting the PSF degradation induced by gravity during alignment/integration, testing and calibration. Both MA support system and gravity release are considered together at the same time in **RD6, i**n continuity with AIT facility.
R35	The XRS Facility shall also offer a removable gravity-release structure / mechanism to counteract the gravity effects on the MA structure in accordance with SOW [AD1].	C	MA distortions related to gravity release, for different possible support patterns, have been investigated by FEA. Consequent MM misalignments have been then post-processed by raytracing, to assess the impact on PSF. The minimum PSF degradation is obtained by six axial supports along the outer ring and six inner supports at the intersection between ring 6 and the spokes (**RD6**).
R38	The detector shall be compatible with operations in high vacuum conditions (as per requirement R15).	C	Detector system is described in **RD5**. Currently we have two options which are both fully compatible with the required vacuum conditions.
R39	The detector and its (*x, y, z*) stage shall be designed in compliance with the requirements in SOW [AD1], and with reference to SOW [RD3], [RD4].	C	The design solution for the XYZS involves the use of a hexapod for the detector fine positioning along x, y and z, according to the requirements. For the purposes of direct beam measures (i.e. flat field), if free space at the centre of the MA is not made available, the hexapod may be mounted on a support that can be moved along a longitudinal track. In its turn, the track is mounted on a central pin that allows a 360° rotation. In this case, the combination of longitudinal translation and rotation of camera and hexapod assembly will allow covering all the points in a circle of more than 240 cm diameter (**RD5**).
R40	The detector shall be placed at the focal plane of the MA.	C	The XYZS can move the detector camera along the z axis, for the range derived from the requirements i.e. 100 mm (1 mu steps). This allows to place the detector in the MA focal plane (**RD5**).

Req. ID	Requirement definition (with post-SRR updates)		NOTES
R41	The detector shall be mounted on a high-vacuum compatible (*x, y, z*) translation stage, for focus alignment (by adjusting position in the *z*-direction, i.e. along the direction of the optical axis of the MA), and for out-of-field acquisitions (by moving the detector on the *x-y* plane).	**C**	The XYZS is designed to provide the needed accommodation for the detection camera. It shall be vacuum compliant, and it will provide a fine positioning of the detector along the x-y-z axis, for the ranges derived from the requirements (**RD5**).
R42	The detector (x, y, z) stage shall move in the z-direction of at least ±50 mm, with steps of 0.25 mm or larger, and with an accuracy ≤ 0.25 mm. The distance from the detector to the MA along the beam axis shall be known with an accuracy of 0.25 mm, with a confidence level of 99.73% (3σ).	**C**	The XYZS is designed to provide a translation of the detector along z axis on a range of ± 50 mm (10 cm). Hexapods can achieve a minimum incremental motion of 1 μm, as well as an equivalent repeatability (**RD5**). The distance of the MA and the detector is controlled by linear displacement metrology with the required accuracy (**RD3**).
R43	The detector (*x, y, z*) stage shall have sufficient translation range in the *x* and *y* direction to allow out-of-field measurements up to at least ±180 arcmin.	**C**	The requirement is defined according to the need of performing out-of-field measurements giving the fraction of out-of-axis X-ray flux falling within the detector field of view (FOV). To achieve compliance the XYZS shall provide a fine positioning of the detector along the x and y axes on a range corresponding to FOV area. This is equivalent to a translation of ±70 mm (14 cm) along both the axes.
R44	The XRS Facility shall be equipped with systems (e.g. crane) and suitable interfaces to lift and manoeuvre MA to be placed in the vacuum chamber and fixed in its position.	**C**	The assembly represented by the MA and the gravity release is transported form the AIT facility to the VERT-X facility using a handling trolley (**RD10** and references herein).
R45	The Contractor shall foresee and report all the optical, mechanical, electrical and electronic equipment needed to run the XRS Facility, including computer systems to control any operation and to acquire and store testing data.	**C**	
R46	The XRS Facility infrastructure shall include, in addition to the vacuum chamber, at least - An air-lock/clean-room ISO 5 connected with the vacuum chamber; - As a goal: A room for the receipt, storage and handling of the MA (dimensions of MA container reported in SOW [AD1); - As a goal: A control room for operating and controlling the XRS and the vacuum chamber and for data collection; - As a goal: A meeting room for at least 20 people; - As a goal: Offices and rooms as needed to support the foreseen operations and operators.	**C**	In continuity with AIT facility In continuity with AIT facility In continuity with AIT facility In continuity with AIT facility In continuity with AIT facility
R49	The MA shall be handled, if outside of the transport container and without protective covers, in an ISO 5 (at least) environment at all times.	**C**	In continuity with AIT facility

Req. ID	Requirement definition (with post-SRR updates)		NOTES
R50	The XRS Facility shall allow to execute the performance verification campaign tests for the MA QM/FM verification campaign, and the calibration campaign for the MA FM, in the modality and schedule as required in SOW [AD1], with reference also to SOW [RD4] and [RD5].	**C**	A preliminary verification and calibration plan is presented in **RD11**. This is fully compliant with calibration requirements (**AD4**, **AD5, AD6**).
R51	The XRS Facility design shall be compliant with the European safety regulations.	**C**	All the electrical plants and mechanisms are designed in accordance with the applicable norms.
R52	The useful lifetime of the XRS Facility (equivalent to full life) is the sum of operational life and shelf life. The XRS Facility useful lifetime shall be a minimum of 15 years considering an average usage of the XRS Facility of about seven (7) months/year, i.e. about 1000 hours/year, and considering regular maintenance as required by the different items.	**TBC**	
R53	The XRS Facility shall allow preventive maintenance to maintain the functions and performances of the system during its lifetime.	**C**	The RAMS analysis is the modelling instrument that is used to identify the preventive maintenance. MTBF values of all the parts of the system must be collected to work out the spare parts list.
R54	The XRS Facility design shall favor the procurement of parts from European manufacturers, manufactured in Europe or at least available in Europe.	**TBC**	

Table 3-1: VERT-X requirements compliance matrix

-- END OF DOCUMENT –