W. M. Keck Observatory

Technical Specification for the Laser System of the Next Generation Adaptive Optics Facility on the Keck II Telescope

Keck Adaptive Optics Note 690

Issue: 1 __

November 16, 2009

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REVISION HISTORY

Revision	Date	Author (s)	Reason for revision / remarks
1	Nov. 16, 2009	All	First issue

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ACRONYMS

4LGSF	Four Laser Guide Star Facility
AD	Applicable Document
AO	Adaptive Optics
AOF	Adaptive Optics Facility
CE	Conformité Européenne (European Conformity)
COTS	Components Off The Shelf
CW	Continuous-Wave
D&AC	Diagnostic and Auxiliary Control
E-ELT	European Extremely Large Telescope
EMC	Electromagnetic Compatibility
ESO	European Southern Observatory
GLAO	Ground Layer Adaptive Optics
HW	Hardware
ICD	Interface Control Document
LCR	Laser Clean Room
LCU	Local Control Unit
LRU	Line Replaceable Unit
LTAO	Laser Tomography Adaptive optics
LTS	Launch Telescope System
MLE	Maximum Likely Earthquake
MTBF	Mean Time Between Failure
OBE	Operational Base Earthquake
PDR	Preliminary Design Review
P-P	Peak to Peak
QCW	Quasi-CW
RAMS	Reliability, Availability, Maintainability and Safety
RMS	Root Mean Square
RD	Reference Document
SHG	Second Harmonic Generation

SIL	Safety Integrity Level
UPS	Un-interruptible Power Supply
UT	Unit Telescope
VLT	Very Large Telescope

Acronym/Abbreviation	Definition
ANSI	American National Standards Institution
COTS	Commercial Off-The-Shelf
DDR	Detailed Design Review
FSD	Full Scale Development
GUI	Graphical User Interface
HVAC	Heating Ventilation Air Conditioning
ICD	Interface Control Document
I&T	Integration and Test
KAON	Keck Adaptive Optics Note
LGSF	Laser Guide Star Facility
LSE	Laser Service Enclosure
MSDS	Material Safety Data Sheet
NGAO	Next Generation Adaptive Optics System
OPS	Operations Team
ORR	Operational Readiness Review
PDR	Preliminary Design Review
PSD	Position Sensing Diode
TBD	To Be Determined
WMKO	W.M.Keck Observatory

1 SCOPE

This document defines the Technical Specifications for one Laser Unit of the Laser System for the Next Generation Adaptive Optics (NGAO) Facility. This document is intended to be as identical as possible to the Technical Specifications for the Laser System of the Four Laser Guide Star Facility (RD1). Specifications that are different between these two documents are underlined in this document.

These Technical Specifications establish the performance, design, development and test requirements which apply to the NGAO Laser System.

These Specifications cover furthermore the Integration, Service and Test equipment which are necessary for the maintenance and the testing of the Laser System.

2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

The following documents of the exact issue shown form part of this Technical Specification. In case of discrepancies between the applicable documents and the present document, the latter will apply with precedence. The letter K for Keck is used in the applicable document number to distinguish these documents from the ESO 4LGSF applicable documents. The "AD" numbered documents are the same as in the ESO 4LGSF Technical Specifications.

Number	Document Title	Document Number	Replaces ESO 4LGSF
KAD1	WMKO NGAO Laser Interface Control Document	To be produced.	AD1 to AD4
KAD2	WMKO Instrument Baseline Requirements		AD5 to AD10, AD13
KAD3	Standard Practice for System Safety	MIL-STD-822D	AD11
KAD4	National Consensus Standard For Configuration Management	EIA-649-A 2004	AD12
KAD5	Standard for Software Verification and Validation	IEEE 1012-2004	AD12
KAD6	Systems and software engineering – Software life cycle processes	ISO/IEC 12207:2008	AD12
KAD7	Systems and software engineering – System life cycle processes	ISO/IEC 15288:2008	AD12
KAD8	Standard for Software Configuration Management Plans	IEEE 828-2005	AD14
KAD9	Programming Languages – C++	ISO/EEC 14882:2003	AD15

KAD10	LabVIEW™ Development Guidelines	National Instruments Part Number 321393D-01; April 2003	AD15
KAD11	Occupational Safety and Health Standards	OSHA Title 29 CFR Part 1910	AD16 to AD18
KAD12	WMKO Emergency Stops System Implementation Requirements		AD25
AD18	Safety of laser products – Part 1: Equipment classification, requirements and user's guide	IEC 60825-1, Ed. 1.2	
AD19	Safety of laser products – Part 4: Laser Guards	IEC 60825-4, Ed. 1.2	
AD20	Safety of laser products – Part 5: Manufacturer's checklist for IEC 60825-1	IEC/TR 60825-5, Ed. 2.0	
AD21	Safety of laser products – Part 5: Manufacturer's checklist for IEC 60825-1	IEC/TR 60825-5, Ed. 2.0	

Table 1: Applicable Documents

AD19 through AD21 are accepted as is with the addition of the following reference: The laser system safety compliance is defined in accord with FDA document 1346 "Laser Products - Conformance with IEC 60825-1 and IEC 60601-2-22; (Laser Notice No. 50)". Vendor is required to produce and file a report compliant with form FDA 3632 "Guide for Preparing Product Reports on Lasers and Products Containing Lasers", dated July 2007. The laser system must be labeled in a manner that is compliant with CDRH 1010.2, 3 and 1040.10.

AD22 is replaced by the following WMKO references:

Source (Organization or Standardizing Body)	**Number**	**Title**
Underwriters Laboratories Inc.	Standard for Safety 508	Industrial Control Equipment
National Electric Manufacturers Association	250-1997	Enclosures for Electrical Equipment (1000 Volts Maximum)
National Fire Protection Association (NFPA)	NFPA 70, 2008 edition	National Electric Code

AD23 and AD24 are replaced by the following WMKO references:

Source (Organization or Standardizing Body)	**Number**	**Title**
IEEE	1228-1994	Software Safety Plans
Underwriters Laboratories Inc.	Standard for Safety 1998	Standard for Software in Programmable

		Components
IEC	IEC 61508-1	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements

The following additional applicable documents may need to be added:

Source (Organization or Standardizing Body)	**Number**	**Title**
ATA	Spec 300-2001.1	Specification for Packaging of Airline Supplies
CENELEC	EN 61000-6-1:2001	Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments
Department of Defense	MIL-STD-464A	Electromagnetic Environmental Effects, Requirements for Systems
Department of Defense	MIL-STD-810F	Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
FCC	Title 47 CFR Part 15	Radio Frequency Devices
IEEE	802.3U revision 95	Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method & Physical Layer Specifications: Mac Parameters, Physical Layer, Medium Attachment Units and Repeater for 100 Mb/S Operation (Version 5.0)
National Institute of Standards and Technology	NIST 811, 2008 edition	The NIST Guide for the use of the International System of Units.
Radio Technical Commission for Aeronautics	DO-254	Design Assurance Guidance for Airborne Electronic Hardware
TIA/EIA	TIA/EIA-568-B	Commercial Building Telecommunications Cabling Standards
TIA	TIA-485	Electrical Characteristics of Generators and Receivers for use in Balanced Digital Multipoint Systems
Underwriters Laboratories Inc.	Standard for Safety 94	Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

2.2 Reference Documents

The following documents contain information relevant to the WMKO Laser System, but are not applicable to this document. The letter K for Keck is used in the applicable document number to distinguish these documents from the ESO 4LGSF applicable documents.

Number	Document Title	Document Number
KRD1	Very Large Telescope Adaptive Optics Facility - Technical Specification for the Laser System of the Four Laser Guide Star Facility	VLT-SPE-ESO-16870-4528 Issue 2 – June 25, 2009
KRD2	The W. M. Keck Observatory Laser Guide Star Adaptive Optics System: Overview	PASP 118: 297-309 (2006)
KRD3	Astro2010 NGAO Activity Report	KAON 649 (April 1, 2009)
RD7	"Sodium D Line Data", D. A. Steck	available at http://steck.us/alkalidata (revision 2.0.1, 2 May 2008)
RD8	Lasers and laser-related equipment – Testt methods for laser beam widths, divergence angles and beam propagation ratios – Part 1: Stigmatic and simple astigmatic beams	ISO 11146-1:2005

3 INTRODUCTION

3.1 Keck Telescope

The Keck Telescopes comprise two 10m telescopes located on the summit of Mauna Kea on the island of Hawaii.

3.2 Current and Near-term Keck Laser Guide Star Facilities

In 2004 WMKO brought into operation a Laser Guide Star Facility (LGSF) on the Keck II telescope which provides an artificial reference star for three AO instruments – NIRC2, NIRSPEC and OSIRIS. The LGSF projects a 14W, 589-nm pulsed dye laser beam into the sky and creates an artificial reference star in the mesospheric sodium layer at an altitude of approximately 90 km. The Nd:Yag pump laser and the dye master oscillator are located in an enclosure on the dome floor. Light from the dye master oscillator is transmitted through a single mode fiber to a laser table located on the elevation ring of the telescope, where two additional stages of dye amplification occur before the laser is projected to the sky through a 50 cm projection lens located at the side of the top end of the Keck telescope. More details of this system can be found in KRD 2. This facility mounted on the Keck II telescope is shown in Figure 1.

In 2010 WMKO plans to put into operation a LGSF on the Keck I telescope which will provide LGS correction for OSIRIS (which will be moved from Keck II) as well as the Keck Interferometer which combines the AO-corrected light from the two Keck telescopes. The LGSF will consist of a 35W mode-locked CW laser mounted on the Nasmyth platform of the telescope. Light from the laser will be transported through single mode photonic crystal fibers to a 50 cm launch telescope located behind the Keck telescope secondary mirror.

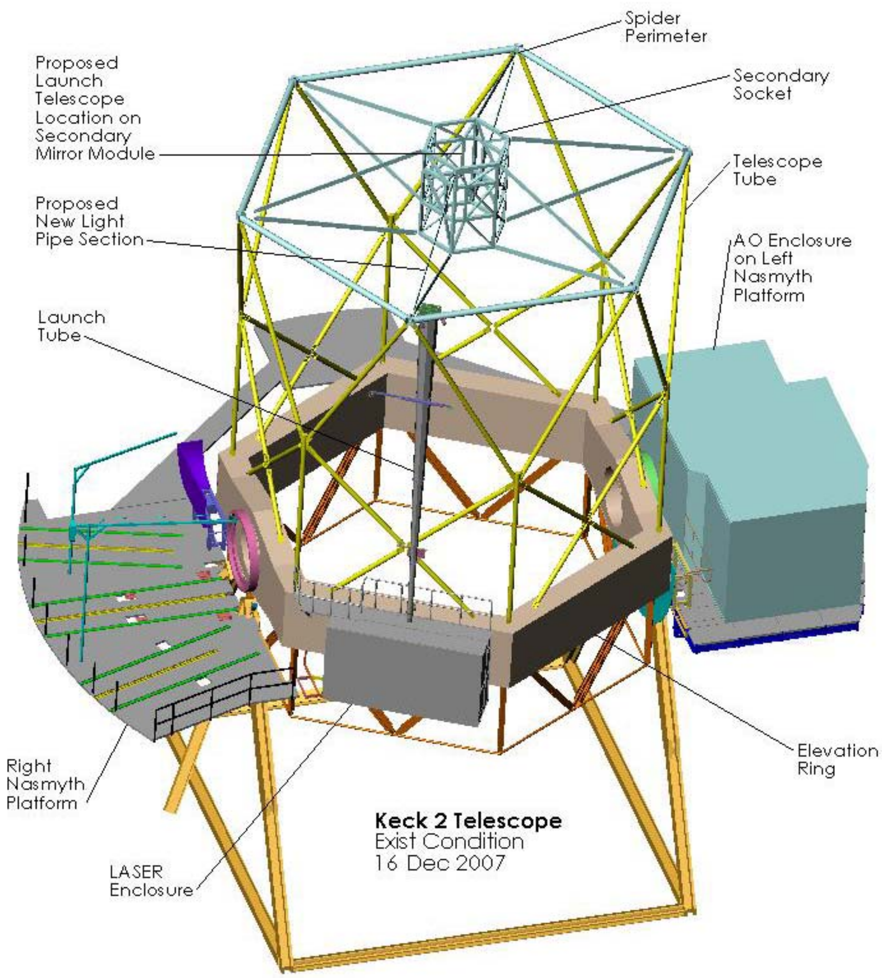

Figure 1 Existing Keck II telescope and laser enclosure location.

3.3 Next Generation Adaptive Optics Facility

An overview of the WMKO Next Generation Adaptive Optics (NGAO) facility can be found in KRD3.

3.4 Next Generation Laser Guide Star Facility

The choice of laser significantly impacts the location of the laser on the telescope and the approach to laser beam transport. The current planned location for beam transport simplicity and for maximizing the laser power delivered to the sky is on the elevation moving portion of the telescope. This plan includes placing the first Laser Unit in the existing Keck II telescope laser enclosure (LE) located on the outside right front face of the elevation ring as shown in Figure 1. Laser Unit/System electronics could be either located in this enclosure or preferably in the AO electronics room on the left Nasmyth platform of the telescope. The AO electronics room is thermally controlled to maintain equipment at a constant 15°C.

The LE (Figure 2) currently supports the operation of the Keck II dye laser amplifiers, housed within this enclosure. The elevation ring, along with the laser enclosure, will rotate, creating a changing gravity vector for the lasers components. The LE's exterior is 4600mm W x 1200mm D x 2600mm H. The exterior panels of this enclosure can be removed as a single unit leaving the floor attached. Other than the floor, the 4 sides (top, left, right, and front), are not structural rigid and cannot support equipment. Only the face of the elevation ring is sufficiently rigid and can support the laser components.

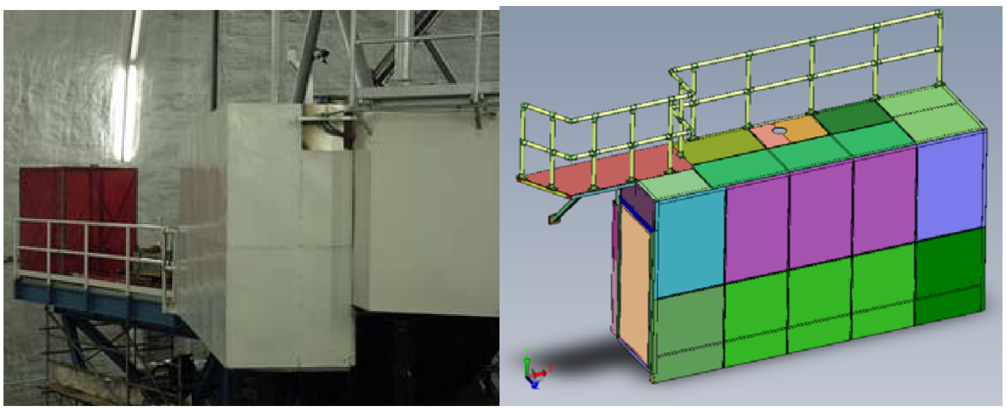

Figure 2: Laser Enclosure

As a comparison, an optical bench is attached to face of the stiffened elevation ring at this location. The optical bench supports the final dye amplifiers of the current Keck II laser system. This 1829mm wide x 1524mm high x 305mm deep optical bench is estimated to weigh 1000 Kg. The bench is supported by a bracket attached at eight locations. This bracket is then attached to six pads attached to the structure of the elevation ring (Figure 3).

Figure 3: Keck II dye laser amplifiers

In the current design, a single Laser Unit will send its beam through the LGSF beam transport system to the launch telescope located behind the Keck telescope's secondary mirror. In the final NGAO system configuration, a combination of three Laser Units will be necessary to send three beams to a multi-LGS generation system and launch telescope behind the secondary. A Laser Switchyard (LS) will be located within the LE to interface with the lasers. The purpose of the LS is to format the beams and prepares them for launching into the beam transport optical system. A depiction of the LS is shown in Figure 4. The LS sits in the middle of the three lasers. It is not necessary for the lasers to enter the LS symmetrically as the figure shows. There is flexibility in the design of the LS to combine the beams into an asterism of three beams.

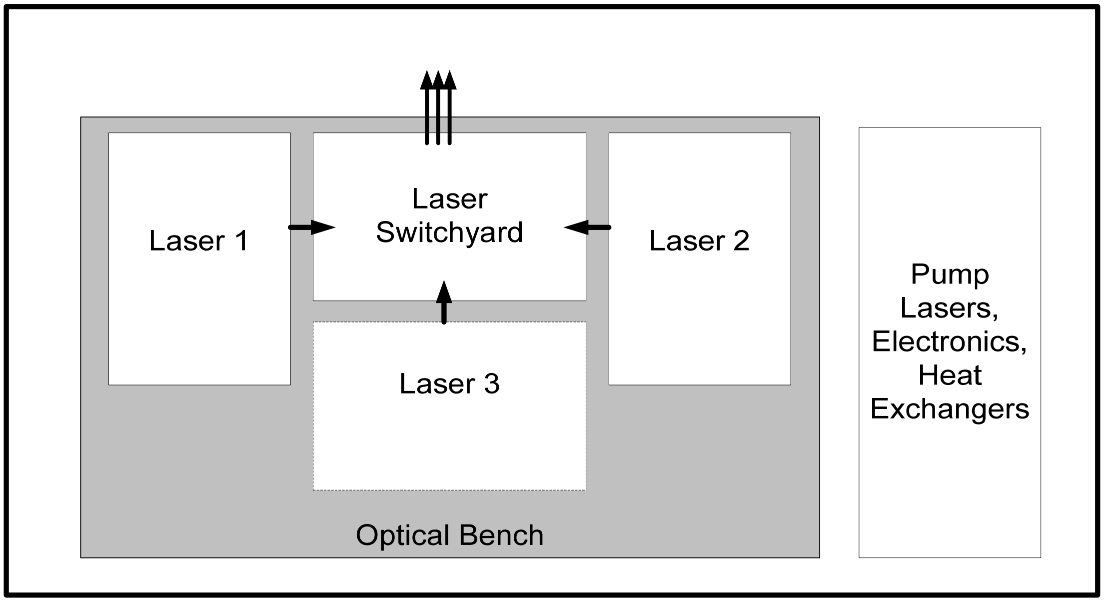

Figure 4: Laser and Laser Switchyard

Supporting equipment for the lasers such electronics, pump lasers, and heat exchangers can be located at several locations. For equipment that must be in proximity of the laser heads, they may be located within the LS as shown in Figure 4. This LS area is limited by both size and the amount of mass that can be attached to the elevation ring. The second location for laser auxiliary equipment is the Left Nasmyth Platform (LNP) in the AO electronics enclosure. The two limitations of the LNP is the distance to the laser heads and its vibration impact. The distance between laser heads and the LNP is 31m. It is extremely desirable for all rotating equipment to be off of the telescope. If it is possible, the third location for auxiliary equipment is the Keck II mechanical room, located 100m from the location of the laser heads.

3.5 Thirty Meter Telescope

The WMKO laser defined in these specifications is intended to be a prototype and risk reduction activity for the Thirty Meter Telescope (TMT) project.

3.6 The Laser System

Each Laser Unit of the Laser System provides a high-power, diffraction-limited and polarised 589 nm laser beam, locked in frequency to the sodium D_2 line. The Laser System is composed of a number of individual Laser Units, probably 3 or 4 depending on the technology used, that could be based on one of the following technologies:

- 1178nm fibre lasers (obtained via Raman shifting or using rare earth-doped fibres), feeding one or more 589nm generation channels using Non Linear Crystals, which are then coherently or incoherently combined.

- 1178nm fibre lasers (Raman shifting or using rare earth-doped fibres), coherently or incoherently combined to feed all the IR power to a single second-harmonic generation (SHG) cavity per LTS.
- VECSEL 1178nm type lasers, with intra-cavity 589nm generation, with the possibility to coherently or incoherently combine the 589nm output channels.
- Free space solid state lasers, with Sum-Frequency of 1319nm and 1064nm laser beams in doubly-resonant cavity.

This list is not exclusive.

Because of the harsh and remote location at the W.M. Keck Observatory and the restricted size and mass that can be accommodated, the laser design shall be optimised for compactness, ruggedness and ease of maintenance.

4 LASER SYSTEM REQUIREMENTS

4.1 Definitions and Conventions

4.1.1 General definitions

In the present document, some requirements are tagged with “goal”, “TBC” or “TBD”. These terms have to be understood as follows:

- **“Goal”** means that the value specified is desired for optimal performance of the Laser System, but might over-constrain the design or be uneconomic. The contractor shall demonstrate reasonable efforts to reach this specification level but not bound to it. In case of failure to reach, he must provide an explanation.
- **“TBC”** (to be confirmed) indicates that the specified value is the result of a preliminary assessment which is currently under review at ESO. In case the specified value is critical or over-constraints the design, the Contractor can propose a different value to which he can commit. TBC values will be confirmed at the time of the Kick-Off Meeting.
- **“TBD”** (to be defined) indicates that ESO will define the requirement as soon as the results of on-going internal studies are available, in cooperation with the Contractor.

4.1.2 Conventions

- **Elevation angle**: The elevation angle is the angle between the telescope tube structure and the horizon. It is equal to 0° when the telescope is pointing towards the horizon and 90° when pointing towards the zenith.
- **Laser System or Laser Unit**~~: The Laser System refers to the complete laser for the 4LGSF.~~
- ~~**Laser Unit**: The Laser Unit refers to the individual lasers.~~

Since WMKO currently only requires 1 laser the terms “laser system” and “laser unit” are equivalent.

4.1.3 Laser definitions

The following definitions are applicable throughout the current document.

4.1.3.1 Beam waist

The laser beam waist is defined, on each major axis, following the second moment of the power spatial density distribution, i.e., the $1/e^2$ diameter of a Gaussian spatial distribution having the same second moment, as on that axis in question (see [RD8]).

4.1.3.2 Laser line width FWHM

The laser line width FWHM is defined by the second moment of the power spectral density $S(f)$:

$$FWHM = 2\sqrt{2\,ln(2)}\sqrt{\frac{\int (f - f_c)^2\, S(f)\,df}{\int S(f)\,df}}$$

where f_c is the centre frequency. In the case where the spectrum consists of a comb of equally spaced lines, the emitted linewidth is defined as the FWHM of a Gaussian profile having the same second moment as the envelope enclosing the emitted lines (or comb), and not that of the individual lines.

4.1.3.3 Sodium characteristics

Figure 4-1 presents the Doppler broadened sodium profile at the temperature of the mesosphere (solid line). The two dashed curves represent, from left to right, the sodium D_{2a} line and the near-D_{2b} centred line.

The nominal D_{2a} line is defined as between $\pm$ 1GHz about the peak of the D_{2a} transition (0 frequency on Figure 4-1), and the D_{2b} line is defined as nominally, any frequency in the range 1 - 3 GHz bluer than the peak of the D_{2a} transition.

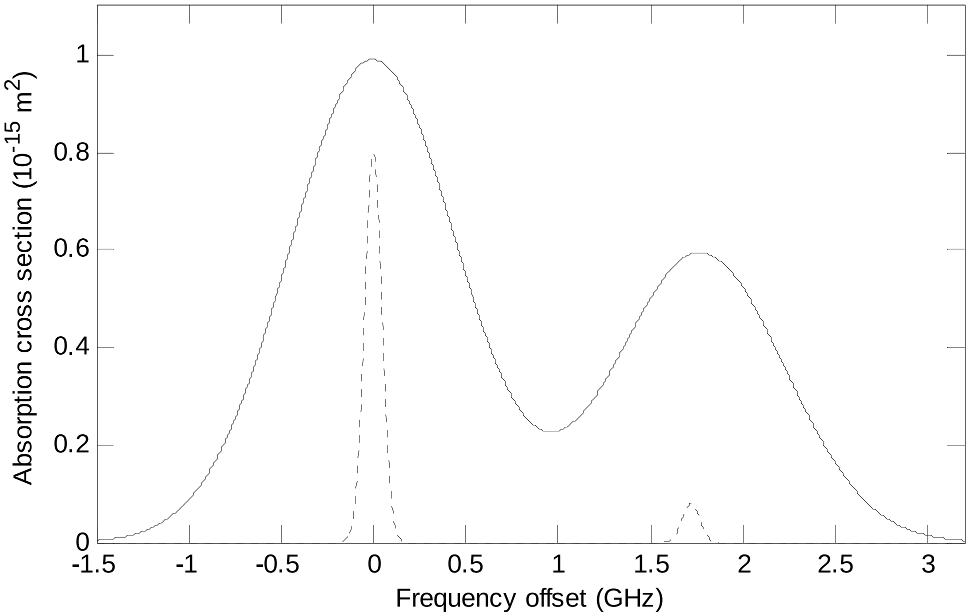

Figure 4-1: Solid curve: Absorption cross section for the Doppler-broadened sodium D_2 line at *T* = 200 K. The frequencies are shown relative to the $3S_{1/2}(F=2) \rightarrow 3P_{3/2}(F=3)$ resonance for low-power unpolarised radiation (after Milonni [P.W. Milonni, R.Q. Fugate, J.M. Telle, "Analysis of measured photon returns from sodium beacons", JOSAA 15, pp.217–233 (1998)], Fig. 2). The left peak corresponds to the D_{2a} line, the right one to the D_{2b} line. Dotted curve: Example of a superimposed laser spectrum tuned to the centre of the D_{2a} line, with a second, weaker, line 1.70 GHz towards the blue for back pumping.

4.2 Product Definition

REQ 1 The Laser System shall comprise one Laser Unit to produce the laser beam.

REQ 2 One laser beam shall be delivered to the Launch Telescope System (LTS).

~~***REQ 3***~~ Not applicable. ~~In case only one or two Laser Units are used, a beam splitter system shall be used to feed the four LTS. Any required beam splitter system shall be part of the Laser System.~~

REQ 4 The laser beam shall be delivered to the LTS as a free space beam.

~~***REQ 5***~~ Not applicable. ~~In case the laser beam is delivered to the LTS via single mode fibres, the fibres shall be part of the Laser Units and all specifications shall be met at the output of the fibres.~~

4.3 Product Breakdown

The Laser System comprises the following major components:

1. The Laser Units including as a minimum
   - The Laser Head
   - The Laser Control System (including Control Software)
2. The Laser System auxiliary equipment, including
   - The Laser Unit Handling Tools
   - The Laser Unit Maintenance Tools
   - The Laser Unit Transport and storage container
3. The Laser System Documentation

REQ 6 A detailed product breakdown shall be established based on the above structure. Each Laser System shall include all components and subsystems needed to meet the requirements. Any tools or handling equipment unique to the laser system shall be supplied with the system.

4.4 Interfaces Definition

4.4.1 Mechanical interfaces

4.4.1.1 Physical Layout Requirements

REQ 7 The complete Laser System shall be mounted on the outer front right side of the Keck II telescope elevation ring (elevation ring = centrepiece). The gravity vector is not constant in this case. Each Laser Unit can be either assembled inside one or two electronics cabinet(s) (per Laser Unit) attached to the *side* of the elevation ring. Additional space is also available for an electronics cabinet and a Cooling Unit on a Nasmyth Platform. The majority of the electronics should be located on the Nasmyth platform. See section 3.4.

4.4.1.2 Allowed design volume

REQ 8 The Laser System (without its electronics and heat exchangers) design shall be compliant with the allowed design volume of 0.6 m x 0.6 m x 0.4 m (TBC).

REQ 9 The mechanical design volume available to the side of the centerpiece is 3.6 m wide x 2.1 m high x 0.4 m deep.

REQ 10 Not applicable. ~~The mechanical design volumes available on the top of the centerpiece are defined in [**Error! Reference source not found.**] and [**Error! Reference source not found.**].~~

REQ 11 In case a liquid-liquid heat exchanger is required, it shall be installed on the Nasmyth Platform (at a distance of 31m) or preferably in the Keck II mechanical room (at a distance of 100 m).

4.4.1.3 Mass and Centre of Gravity

REQ 12 The Laser System maximum allowed mass is limited to 1000 kg/Laser Unit on the centerpiece.

REQ 13 The centre of gravity of the Laser Units on the centerpiece shall be at max. 0.15m (**TBC**) from the centerpiece installation surface.

4.4.2 Power supply interfaces

REQ 14 The total non-UPS power provided to the Laser Unit is shown in Table 2. Any larger or differently managed power requirement for the Laser Unit requires WMKO approval.

Table 2: Laser Unit Power

Parameter	*Min.*	*Typ.*	*Max.*	*Units*	*Notes*
Voltage	187	208	229	Vac	1
Current	-	-	40	Amperes	2
Frequency	57	60	63	Hz	
Power factor	0.6	-	-	-	

Notes:

1. Voltage given is phase to phase for a three phase, 4 wire and ground service.
2. Two 20A circuits.

REQ 15 The total UPS power required by the Laser System shall never exceed 5 kVA with an overall power factor $\lambda > 0.85$. Any larger or differently managed power requirement for the Laser System requires WMKO approval.

REQ 16 The acceptable mechanical interfaces for the power distribution shall be the following:

- A locking, panel mounted UL listed ac power inlet connector.

4.4.3 Control Interfaces

REQ 17 The Laser System operation shall be controlled through the following interface:

a. Ethernet interface

REQ 18 Not applicable.

REQ 19 Not applicable.

REQ 20 The Ethernet interface shall operate with 100BASE-TX media with an RJ45 connector. The interface shall be self-sensing.

REQ 21 Optional for WMKO. To ease diagnosis, the following signals shall be added as digital IO independent from the main communication interface:

- "Watch-dog" signal to verify that the system is "alive".
- The error condition signals to detect failures of the Laser System control SW.
- A reset line for the main communication interface and for the Laser Unit.

The contractor shall identify (and eventually add) if additional signals are necessary. They can be either digital IO for monitoring and control of the Laser System or analog IO for advanced diagnostic and fine tuning. The interfaces shall be in compliance with the specifications in sections 4.4.4 and 4.4.5.

4.4.4 Diagnostic and auxiliary control (D&AC): Analog Interfaces

Not applicable. ~~In case it is requested by the Laser System to have links with 4LGSF through any analog IO signals (see for example section 4.4.6) their interface should be as following:~~

REQ 22 ~~Analog D&AC signals shall be current signals with 4-20mA range.~~

REQ 23 ~~Each signal will consist of 2 lines, the signal line and the return line.~~

REQ 24 ~~The maximum equivalent resistance of an input stage will be 500Ω.~~

REQ 25 ~~The maximum load to an output stage will be 500Ω.~~

REQ 26 ~~The analog interface shall be galvanic insulated from the inner circuitry of the Laser Units. Adequate protections against ESD, over-voltage, reverse polarity and over load shall be foreseen.~~

REQ 27 ~~Connectors shall be compliant with one of the following standard: MIL-C-28748, MIL-C-26482, MIL-C-24308 B or MIL-C-5015. The last pin is reserved for the eventual supply ground, while the first for the supply Vcc even if they are not used by the analog interface.~~

4.4.5 Diagnostic and auxiliary control (D&AC): Digital Interfaces

In case it is requested by the Laser System to have links with the Keck LGSF through any digital IO signals (see for example section 4.4.6) their interface should be as following:

REQ 28 Digital (logic) signals will consist of 2 lines A and B. When the 2 lines are in electrical connections the signal has a logic level 1 otherwise 0.

REQ 29 The electrical connection between the 2 lines of a digital signal can be generated either by a mechanical contact (relay) or by a transistor (e.g. output stage of opto-couplers).

REQ 30 The equivalent circuit for an output stage is a short circuit for logic level 1 and an open circuit for logic level 0.

REQ 31 The input stage will not force a voltage greater than 24V between the lines A and B when the logic level is 0.

REQ 32 When the logic level is 1 the input stage will force a current flow from the line A to the line B. The acceptable current range is 0÷20mA.

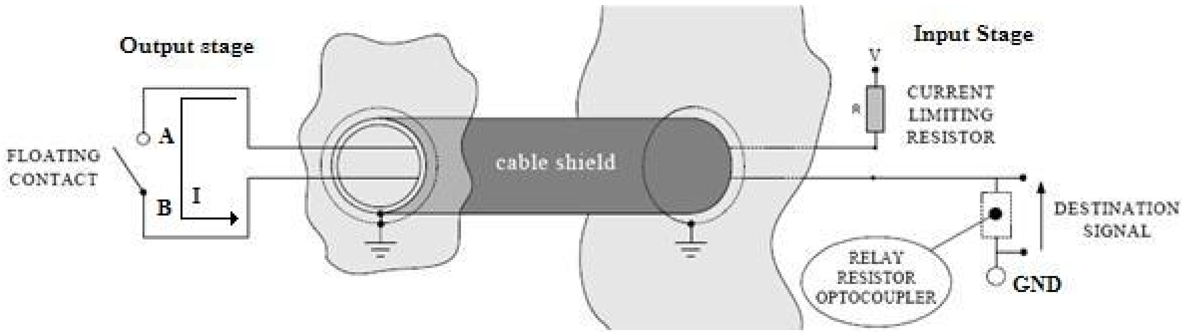

Figure 4-2: Example of digital connection.

Figure 4-2 shows an example of a digital connection from a generic output stage (either laser or field connection) to a generic input stage (either laser or field connection).

REQ 33 The interface shall be galvanic insulated from the inner circuitry of the Laser Units. Adequate protections against ESD, over-voltage, reverse polarity and over load shall be foreseen.

REQ 34 Connectors shall be compliant with one of the following standard: MIL-C-28748, MIL-C-26482, MIL-C-24308 B or MIL-C-5015. The last pin is reserved for the eventual supply ground, while the first one for the supply Vcc even if they are not used by the interface.

4.4.6 Safety Digital Interfaces

REQ 35 The digital IO for the safety interface shall be designed according to REQ 28 to REQ 34.

REQ 36 All safety systems shall be implemented in manner consistent with MIL-STD-822 "Standard Practice for System Safety". All digital logic employed in the safety system shall be implemented in sequential logic circuits without using a computer or software in a manner consistent with DO-254 "Design Assurance Guidance for Airborne Electronic Hardware".

REQ 37 The safety interface shall use components and architecture of the appropriate SIL (determined by the contractor safety assessment). If the SIL impose more stringent constraints than those specified in REQ 35 ~~and **Error! Reference source not found.**~~ the SIL constraints shall have priority.

REQ 38 At least the following signals shall be part of the safety interface:

- Emission ON — Output — 1 if the Laser Unit is generating laser light
- Safety Status — Output — 0 if an internal safety fault is present
- Emergency Shutdown (level 1) — Input — 0 to stop any light generation

- Emergency Shutdown Input 1 to shutoff power to entire system (level 2)
- Output shutter closed Output 1 is the output shutter is closed
- Output shutter fault Output 0 if there is a fault in the output shutter
- Output shutter permissive Input 1 to allow the output shutter to open
- Exposed Hazardous Radiation Output 1 if there is exposed hazardous radiation; may be represented by the "Safety Status".
- Laser System Fault Output 1 to denote there is an internal fault.
- Laser Interface Fault Output 1 to denote the interface is not operating correctly such as differential signal representing two "1"s or two "0"s.

4.4.7 Liquid Cooling Interfaces

REQ 39 The Laser System shall be operated with the standard coolant delivered at the WMKO and specified as following:

Table 3: Coolant supply conditions and power dissipation

Parameter	***Min.***	***Typ.***	***Max.***	***Units***	***Notes***
Coolant fluid	N/A	N/A	N/A	N/A	1
Supply temperature	-10	0	+3	ºC	2
Coolant pressure	-	45	100	psig	3
Flow rate	-	-	20	l/min	
Pressure drop	-	6	8	psi	
Power dissipation					
To ambient			500	Watts	
To coolant			10,000	Watts	

Notes:

1. 40% by volume Dowtherm SR1 with water.
2. Seasonally dependent. The coolant temperature set point is 3 ºC below the dome ambient air temperature.
3. All laser system cooling system plumbing should be able to withstand a maximum pressure of 100 psig in the event of system pressure regulation failure.

In case these features do not match with the Laser System coolant requirements, a liquid-liquid heat exchanger can be used. It will be part of the Laser System.

REQ 40 In the case a liquid-liquid heat exchanger is necessary for the correct performance of the laser and Laser Units are mounted on the centrepiece, it shall be installed on the Nasmyth Platform or in the mechanical room (see REQ 11).

In this case, the routing of pipes between the liquid-liquid heat exchanger and the corners of the centrepiece shall be defined together with WMKO and be included in an Interface Control Document. The pipes will be implemented by WMKO.

REQ 41 All glycol cooling shall be plumbed with braided stainless steel hose and stainless steel fittings. Custom manifolds shall be used rather than arrangements of "T" fittings and hose. Permanent connections shall be made with JIC 37º flare compression fittings or SAE straight thread O-ring fittings. Teflon tape shall not be used to seal threaded connections. Removable connections shall be made with ½" Parker Hannifin series FS quick disconnect fittings. The supply coupler on the laser system shall be male and the return coupler shall be female. Where required King Instrument Company flow meters and needle valves are preferred for flow metering and control applications. Where variable gravity orientations are encountered a spring loaded variable area flow meter, such as the in-line flow meters manufactured by the Hedland Division of Racine Federated Inc. shall be employed. The Hedland T303 stainless steel models are preferred. All glycol cooling systems shall be provided with a flow switch, Proteus Industries Inc. type 100B110 is preferred, to generate a loss of coolant alarm. This flow switch shall interrupt power to the affected system unless a separate over-temperature detection system is provided to remove power from the affected system.

REQ 42 Not applicable (see Req 39). The pressure drops of each Laser Unit cooling circuit shall be less than 2 bars. In case the design shows a larger pressure drop, it requires WMKO approval.

REQ 43 The cooling system shall be designed to avoid the onset of corrosion which may impact on the Laser System performance or reliability. Whenever possible, components of the cooling system shall be made of stainless steel alloys. Only for the heat exchanger it is allowed to use copper.

4.4.8 Software Interfaces

REQ 44 The Laser System control software shall ensure the control, the failure diagnostics, the maintenance and the house-keeping of the Laser System. The control software functional requirements shall be agreed upon with WMKO during the design phase.

REQ 45 The Laser System shall provide the following type of interface to the WMKO LGSF control system. It will allow the WMKO LGSF to check and monitor the Laser System proper behaviour and performance:

- Commands to bring the Laser System to specific states
- Commands to set configuration parameters
- Query routines to monitor the Laser System: some of this information will be monitored at regular intervals while other will be "queried" on demand. Typically multiple clients have to be supported by the laser controller, to

allow the WMKO LGSF control system to send queries and commands to the laser, at the same time.

- Query to transfer telemetry data captured by the laser system.
- The laser system shall be able to save data remotely on a network.

The parameters and high level functions to be provided by the Laser System software are defined in REQ 44, REQ 47 and REQ 48. At design phase a set of values could be assigned to a single query function according to the frequency these data should be monitored.

REQ 46 The Contractor shall propose a list of functions to control the Laser System. This list shall be agreed upon by WMKO. The Laser System software shall provide as a minimum the following high-level functions:

- Start-up and Shutdown.
- System check to verify that each Laser Unit functions.
- Set servo loop target parameters (if any).
- Set output power.
- Open/Close output shutter.
- Toggle on and off the Laser Unit frequency w.r.t. the sodium D_2 line.
- Lock/Unlock the Laser Unit frequency.
- Calibrate the Laser Unit frequency if necessary.
- Emergency shutdown level 1 and possibly 2.

REQ 47 The Contractor shall propose a list of Laser System parameters to be monitored. The Laser System shall allow querying those parameters at a rate up to 1Hz (to be confirmed during the design phase). This list shall be agreed upon by WMKO. The Laser System software shall allow to monitor as a minimum the following parameters:

- System status (incl. shutter status, servo loops status).
- Faults.
- Safety interlocks status.
- Pump laser drive current (accuracy ≤ +/- 5 %).
- Pump diodes running hours.
- Temperature of cold plates and heaters.
- Servo loops data for offline diagnostics.
- Relative laser powers (pump, output and back-reflected).
- Sodium cell temperature (if used for frequency locking).
- Temperature of crystal oven used for frequency conversion.
- Output emission wavelength, measured with accuracy better than 100 MHz.

REQ 48 In case REQ 84 is fulfilled, the Contractor shall add the supplementary parameter to the list defined in REQ 47. The Laser System shall allow querying the laser spectrum profile at a rate up to 0.1Hz (to be confirmed during the design phase) with a range allowing to distinguish clearly between D2a and D2b lines.

REQ 49 The Laser System maintenance or service software provided by the manufacturer shall allow tuning of operational parameters and performing tests to verify the correct functioning of the Laser System. It shall allow the WMKO LGSF control computer to receive the current configuration parameter data, and to restore a different configuration in the laser controller.

4.4.9 Optical interfaces

REQ 50 Each Laser Unit shall deliver a collimated beam, with an output beam waist diameter @ $1/e^2$ equal to 3.0 mm ± 0.1 mm ~~(goal: fiber delivery with a collimator)~~.

REQ 51 Output beam waist location: 0.0 m ± 2 m w.r.t. output bezel.

REQ 52 ~~The output laser beam position stability, as measured up to 50 Hz in operational conditions, shall fulfil the following requirements:~~

- ~~Pointing ≤ 0.16 mrad RMS (goal ≤ 0.08 mrad RMS).~~
- ~~Lateral shift ≤ 100 µm RMS (goal: ≤ 50 µm RMS).~~

The output laser beam position stability, as measured in operational conditions, shall fulfill the following requirements:

- Short term jitter ≤ 10 µrad RMS (above 20Hz)
- Medium term drift ≤ ±60µrad peak (over 1 minute)
- Long term drift ≤ ±160 µrad RMS (over 12 hours)
- Lateral shift ≤ 100 µm RMS (goal: ≤ 50 µm RMS).

REQ 53 Not applicable.
REQ 54 Not applicable.

4.5 Environmental Requirements

The Laser System will be operated at the Keck II telescope at WMKO.

REQ 55 All parts of the Laser System shall meet the specified performance requirements under the **operational** conditions defined in the following table.

Table 4: Operating Environment

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4300	m	
Temperature					
Range	-10	0	20	ºC	1
Rate of change	-0.8	-	0.8	ºC/h	

Humidity	0	-	90	%	2
Gravity orientation	-	-1	-	g	3
Vibration	-	-	$1x10^{-5}$	g^2/Hz	4
Acceleration	-	-	1	g	5

Notes:

1. Typical value is the average annual temperature.
2. Relative, non-condensing.
3. Normal to the earth's surface.
4. 20 Hz to 1000 Hz, 6db/oct drop- off to 2000 Hz.
5. All axes, due to telescope drive system fault conditions.

REQ 56 N/A

REQ 57 The Laser System shall meet all of the performance specifications without repair or realignment after being subjected to any number of cycles of any of the non-operating environment conditions defined in the following table. These represent environments associated with normal non-operating telescope activities including but not limited to storage and handling within the facility and installation and removal from the telescope.

Table 5: Non-Operating Environment

Parameter	**Min.**	**Typ.**	**Max.**	**Units**	**Notes**
Altitude	0	-	4300	m	
Temperature					
Range	-10	0	30	ºC	1
Rate of change	-0.8	-	0.8	ºC/h	
Humidity	0	-	90	%	2
Gravity orientation	-	-1	-	g	3
Vibration	-	-	$8.0x10^{-4}$	g^2/Hz	4
Shock	-	-	15	g	5
Acceleration					
Due to handling	-	-	-	g	6
Due to seismic activity	-	-	2	g	7

Notes:

1. Typical value is the average annual temperature.
2. Relative, non-condensing.
3. Normal to the earth's surface.
4. 20 Hz to 1000 Hz, 6db/oct drop- off to 2000 Hz.

5. 0.015 second half-sine, all axes.
6. 2 g vertical, 1 g fore/aft, 0.5 g lateral
7. 0.5 Hz to 100Hz, all axes.

REQ 58 N/A

REQ 59 The Laser System shall be designed in such a way that it is possible to put it back in operational condition with no more than 8 hours and 2 manpower resources after the occurrence of the **survival** loads and conditions defined in section 4.8.3 (see REQ 111).

4.6 Operational Modes

REQ 60 The Laser Units shall include five operational modes:

- Off mode
- Stand-by mode
- On mode
- Observation mode
- Maintenance mode

To / From	Off	Stand-by	On	Observation	Maintenance
Off		Yes	No	No	Yes[1]
Stand-by	Yes		Yes	No	TBD[2]
On	Yes[3]	Yes		Yes	TBD[2]
Observation	Yes[3]	No	Yes		No
Maintenance	Yes[3]	Yes	TBD[2]	No	

Table 6: Allowed transitions between the different modes

REQ 61 The state of the Laser System and of its components shall be defined for each of the five operational modes.

REQ 62 All allowed transition steps (transition sequence and intermediate states) between pairs of modes shall be defined according to Table 6.

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[1] Requested for maintenance when fully shutdown

[2] TBD is to be resolved by contractor according to the foreseen maintenance activities of the Laser System. The decision is subject to WMKO approval.

[3] Requested in case of power failure, or emergency shut-down.

4.6.1 Off Mode

REQ 63 The Off Mode corresponds to the time when the Laser System has no power. At the telescope, the maximum time for Off Mode can be unlimited.

REQ 64 During Off Mode the telescope altitude and azimuth axes can move. The elevation angle can be in the range of -6.4° to 94.1°.

REQ 65 During Off Mode, the environmental conditions are defined by REQ 57 ~~and REQ 58~~.

4.6.2 Stand-by mode

REQ 66 The Stand-by Mode corresponds to the time when the Laser System is mounted in the telescope but no observation is performed. It is a power saving mode whereby functions / functional parts which can be switched off without impairing the safety or later performance of the Laser System are powered down. At the telescope, the maximum time in Stand-by Mode can be unlimited.

REQ 67 During Stand-by Mode the telescope altitude and azimuth axes can move. The elevation angle can be in the range of -6.4° to 94.1°.

REQ 68 During Stand-by Mode, the environmental conditions are defined by REQ 57 ~~and REQ 58~~.

REQ 69 The time required for going from Stand-by to On Mode shall be less than 30 minutes. This transition shall be fully remotely controlled.

4.6.3 On Mode

REQ 70 The On Mode corresponds to the time when the Laser System is fully powered and ready for use in Observation Mode. At the telescope, the maximum time for On Mode will be 12 hours.

REQ 71 During On Mode the telescope altitude and azimuth axes can move. The elevation angle can be in the range of -6.4° to 94.1°.

REQ 72 During On Mode, the environmental conditions are defined by REQ 57~~REQ 55 and REQ 56~~.

REQ 73 The time required for going from On to Observation Mode shall be less than 1 minute (goal ≤ 30 seconds). This transition shall be fully remotely controlled.

REQ 74 In On mode, it shall be possible to run a self-test at any time (see section 4.9.2.4).

4.6.4 Observation Mode

REQ 75 The Observation Mode corresponds to the time when an observation is performed. In this mode, the Laser Units are at full power, fulfilling all requirements described in this document. At the telescope, the maximum time for Observation Mode will be 18 hours. The shutter will transition between open and close during the Observation Mode and will take no longer than 1 second with allowance for safety regulations.

REQ 76 During Observation Mode the telescope altitude and azimuth axes can move. The elevation angle can be in the range of 20° to 90°.

REQ 77 During Observation Mode, the environmental conditions are defined by REQ 55 ~~and REQ 56~~.

4.6.5 Maintenance Mode

REQ 78 The Maintenance Mode corresponds to the time when the Laser System maintenance is performed. This mode shall be defined and is subject to WMKO approval. During this mode, the telescope is stationary, access to centrepiece is possible after all safety equipments have been installed and the beam launch is disabled.

4.7 Performance Requirements

4.7.1 Optical requirements

REQ 79 All optical requirements defined in this section shall be fulfilled for each ~~of the four~~ output beam delivered to the Beam Transport System, in observation mode

REQ 80 The Laser Units temporal format shall be CW or QCW.

REQ 81 The Laser Units output emission wavelength shall be stabilised to the peak of the Na D_{2a} line in the mesosphere (see [RD7]) with absolute wavelength accuracy better than ±40 MHz.

REQ 82 In case that REQ 84 and REQ 85 below are fulfilled, the continuously-broadened or multi-line D_{2a} centered envelope line width (see section 4.1.3.2) of the Laser Units shall be ≤ 250 MHz FWHM (goal 5 ± 1 MHz FWHM). In case REQ 84 and REQ 85 below are not fulfilled, the continuously-broadened or multi-line D_{2a} centered envelope line width of the Laser Units shall be 50 ± 10 MHz FWHM (goal 5 ± 1 MHz FWHM). The line width measurement is averaged over 10 ms.

REQ 83 The Laser System shall be designed to deliver simultaneously at each LTS a visible power which is a function of the emitted linewidth and format. The laser delivered power is to be[4] 20 W in case that REQ 84 and REQ 85 are fulfilled. In case they are not fulfilled, the laser power shall be 25 W. ~~In case a fibre beam relay is delivered, these powers are required at the exit of the fibre relay system.~~

REQ 84 As a goal, which WMKO values very much, the Laser Units shall have 10% of their output power (± 1% of the output power) within an envelope contained

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[4] This power is the sum of D_{2a} and D_{2b} emissions.

within the Na D_{2b} line (see section 4.1.3.23) and centred at a frequency 1.713 GHz bluer (higher) than the main power frequency (Na D_{2a} line).

REQ 85 In the case where the goal of REQ84 is fulfilled, for each and any laser line emitted within the D_{2a} envelope, there will be at the same time an equivalent and corresponding line within the D_{2b} envelope shifted by 1.713 ± 0.010 GHz w.r.t. its counterpart within the D_{2a} line. For each of these equivalent and corresponding lines, all other spectral properties (except centre frequency) shall be identical to those emitted within the main D_{2a} line with an accuracy of 10% P-P. In case the D_{2a} centred emission line is a continuously broadened envelope, then the D_{2b} centred emission line will also be continuously broadened. Remaining spectral properties and respective jitters will comply with the same requirements as in the lines-within-an-envelope case.

REQ 86 The Laser Units shall fulfil the following in-band power requirements:

- 90% of the measured output power in the Na D_{2a} line shall be within ± 1 FWHM of the corresponding emission centre frequency.
- 95% of the measured output power in the Na D_{2a} line shall be within ± 2 FWHM of the corresponding emission centre frequency.
- 90% of the measured output power in the Na D_{2b} line shall be within ± 1 FWHM of the corresponding emission centre frequency.
- 95% of the measured output power in the Na D_{2b} line shall be within ± 2 FWHM of the corresponding emission centre frequency.

REQ 87 N/A

REQ 88 The long term power stability shall be ≤ 15% P-P (goal 5% P-P) (the power measurement is averaged over 1 s).

REQ 89 The intensity noise shall be ≤ 6% RMS (goal 3% RMS), on a 10 ms timescale (intensity measurement frequency: 10 kHz).

REQ 90 The Laser beam optical quality measured over an area of diameter √2 times the waist diameter (see REQ 50) shall be ≤ 50 nm RMS (goal: 25 nm RMS)

REQ 91 The output beam asymmetry (ratio of the beam diameters in orthogonal directions) shall be contained in the range 0.93 to 1.07, at all distances from the laser output.

REQ 92 The laser beam shall be linearly polarised, with a polarization ratio ≥ 100:1, goal ≥ 200:1.

REQ 93 The laser beam polarization direction shall be defined as follows:

- for a free-space beam output: off vertical shall be within ± 2°.
- ~~for a fibre delivery: output marking off vertical shall be within ± 2°~~

REQ 94 The polarisation direction variations shall be < 5° P-P when the Laser Unit has reached regime, (the power measurement is averaged over 1 second).

REQ 95 The Laser Units shall be able to simultaneously toggle all emitted lines away from their respective standard centre lines by at least 5 GHz to the blue, within 10 s (goal 5 s) for each toggle, and without changing the remainder of the laser output beam properties by more than 5 %.

REQ 96 During Observation Mode and On Mode, the Laser System shall satisfy all requirements even in case of an up to 10% back reflected optical power at the emitted wavelengths. During Maintenance Mode, the Laser System shall not fail (see REQ 116 for the definition of a failure) under accidental back-reflections of up to 100%.

REQ 97 The total residual optical power, outside of the range 580 ≤ λ ≤ 600nm, shall be less than 10^{-4} of the total output power.

4.7.2 Mechanical requirements

REQ 98 The massive parts of the Laser System assemblies mounted inside the Laser Unit structures shall have their lowest Eigen frequency larger or equal to 70 Hz in the local vertical direction and 30 Hz in the local horizontal directions (vertical axis is parallel to the Keck II telescope tube optical axis, i.e. perpendicular to the top of the centrepiece) when attached to the telescope structure.

Vibration isolation shall be employed as required to isolate sources of vibration within the laser system due to moving components such as fans, pumps and motors.

The laser system shall meet all performance and operating requirements when installed in a vibration environment that conforms to the Generic Vibration Criteria[5] Curve "C" as shown in Figure 3. The laser system shall not produce vibrations that result in rms velocities in excess of those given in curve "C" of Figure 3.

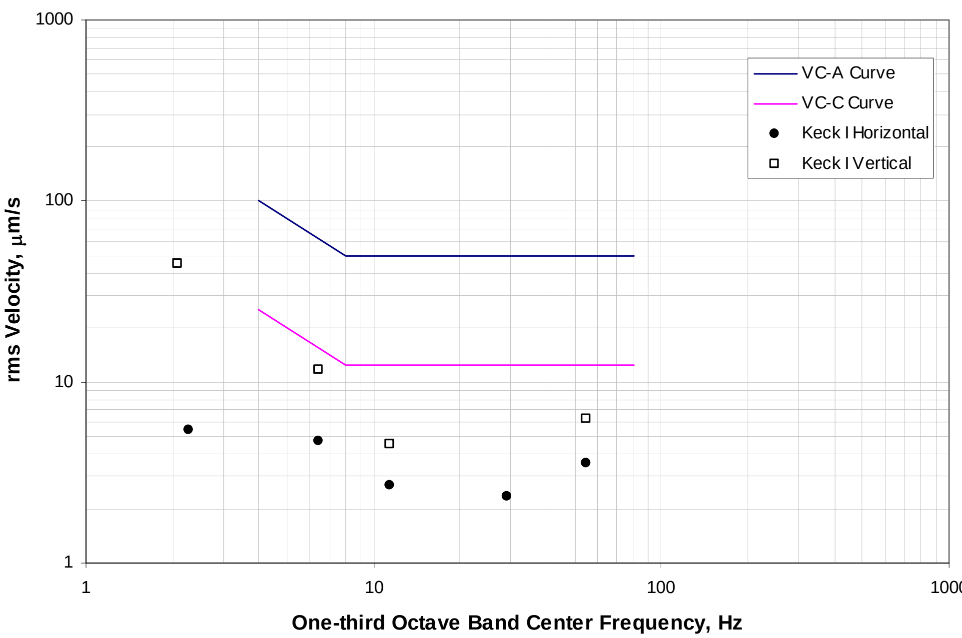

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Figure 3: Keck Telescope Equipment Vibration Limits

4.7.3 Laser Units cooling requirements

REQ 99 The external surface temperature of the Laser Units housings shall remain within ±1.5°C of the ambient air temperature under operational conditions (REQ 55).

REQ 100 Foams used for insulation must be flame retardant and of the closed cell variety with a UL rating of 94V-0 or better.

REQ 101 As a goal, in order not to introduce vibrations in the telescope, the Laser Units cooling system shall not make use of rotating equipment like motors or fans or others. In case it cannot be avoided to use rotating equipments, damping devices shall be used to reduce the vibrations induced in the telescope. The use of these damping devices shall be agreed by WMKO.

REQ 102 The Laser Units components shall be conductively cooled using liquid cooling. Liquid-liquid heat exchangers are also allowed.

4.7.4 Operation requirements

REQ 103 The routine operation of the Laser System shall be remote.

REQ 104 Optional. For maintenance operations only, it shall be possible to operate the Laser Units also locally without the need of an external computer or terminal.

4.8 Environmental Conditions

4.8.1 Telescope Altitude and Azimuth structure speed and acceleration

REQ 105 In operational conditions, the Laser System shall be able to operate with maximum telescope acceleration around azimuth of $\pm 0.4° s^{-2}$.

REQ 106 In operational conditions, the Laser System shall be able to operate with maximum telescope acceleration around altitude of $\pm 0.3° s^{-2}$.

REQ 107 In operational conditions, the Laser System shall be able to operate with maximum telescope angular velocity around azimuth of $\pm 2° s^{-1}$.

REQ 108 In operational conditions, the Laser System shall be able to operate with maximum telescope velocity around altitude of $\pm 1.5° s^{-1}$.

4.8.2 Gravity loads

REQ 109 The Laser System shall be able to operate under gravity load variations according to the Telescope elevation angle as defined in REQ 64, REQ 68, REQ 72, REQ 78.

4.8.3 Design Loads

The load cases to be considered during the Finite Element Analysis are defined here after.

REQ 110 The operational load case is defined as follows:

- Gravity: elevation angle equal to 20° and 90°.
- Thermal: -10°C to 20°C max - Gradient 0.8°C/h.
- Operational vibrations introduced by the telescope environment in all three local axes as defined following REQ 114.

REQ 111 The Operational Base Earthquake (OBE) load case is defined as follows:

- Gravity: elevation angle equal to 20° and 90°.
- Thermal: -10°C to 20°C max - Gradient 0.8°C/h.
- Vibration introduced by Operational Base Earthquake, defined as follows:
  - 1.75 g in the two local Laser Units horizontal directions.
  - 1.4 g in the local Laser Units vertical direction.

REQ 112 The Thermal Survival load case is defined as follows:

- Gravity: elevation angle equal to 0° and 90°.
- Thermal: -10°C to 30°C max. - gradient 0.8°C/h

REQ 113 The Maximum Likely Earthquake (MLE) load case is defined as follows:

- Gravity: elevation angle equal to 0° and 90°.
- Vibration introduced by a MLE, defined as follows:
  - 2.5 g in the two local Laser Units horizontal directions.
  - 2.0 g in the local Laser Units vertical direction.

- For the WMKO lasers the structure of all enclosures supplied with the laser system shall be designed to meet the zone 4[6] earthquake survival requirements of Telcordia Standard GR-63-CORE, "NEBS™ Requirements".

REQ 114 Operational vibrations introduced by the telescope environment are defined by the following spectrum (see Figure 4-4). This curve is a conservative envelope of a single axis vibration PSD, derived from on-site measurements during observation.

This envelope PSD is described in the three different regions as follows:

- $0 \leq f \leq 20$ Hz PSD' = $4.228\ 10^{-10}$ (g^2/Hz)

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[6] The United States Geological Survey (USGS) has assigned the big island of Hawaii to seismic zone 4. The seismic zone system is defined in the "International Building Code" (IBC) published by the International Code Council (ICC) in 2009.

- 20 < f ≤ 100 Hz PSD'' = $6.404\ 10^{-12}\ f^{2}$ (g^2/Hz)
- 100 < f ≤ 1000 Hz PSD''' = $6.404\ 10^{-4}\ f^{-2}$ (g^2/Hz)

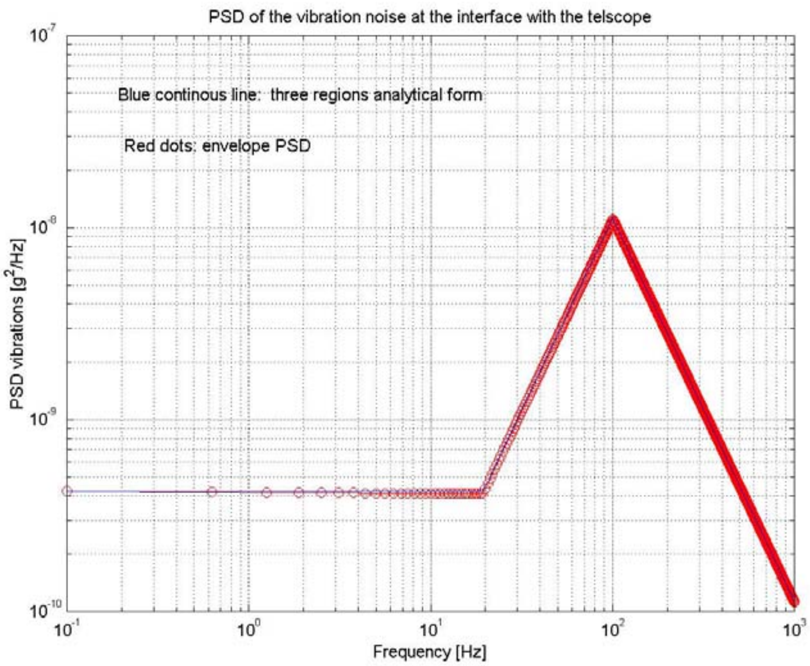


Figure 4-4: Spectrum of the vibration noise introduced by telescope environment at centrepiece level.

4.9 Reliability, Maintainability, Safety Requirements

4.9.1 Reliability requirements

REQ 115 The Laser System shall be designed for a minimum lifetime of 10 years considering 12 hours of Observation and 12 hours of Stand-by per day in the conditions defined in sections **Error! Reference source not found.** and 4.6. A list of the components that could face obsolescence problems will be given. As a goal, the design of the Laser System shall be flexible to allow the replacement of these components in case of obsolescence.

REQ 116 The Mean-Time-Between-Failure (MTBF) of the Laser System in the conditions defined in sections 4.5 and 4.6 and assuming all indicated preventive and corrective maintenance (see section 4.9.2) is carried out, shall not be less than 1 year (goal 2 years).

A failure is defined as a major loss of operation of 5 hours or more during which observing programs cannot be executed. This major loss of operation occurs if one of the following conditions happens:

- The quotient of the laser output power and the square of the Laser Unit is degraded by more than 50% of its nominal one as defined per REQ 83 and REQ 84 and REQ 90.
- ~~The beam quality of one Laser Unit is worse than 2.~~
- The shift between the actual output wavelength of one Laser Unit and the peak of the Na D_2 line is exceeding ± 0.5 GHz.
- The short term intensity noise of one Laser Unit is more than 20% RMS (see REQ 89).

4.9.2 Maintainability requirements

4.9.2.1 Maintenance Approach

~~The maintenance philosophy which ESO has established (**Error! Reference source not found.**) shall be reflected in the design of the Laser System:~~

REQ 117 The maintenance work load and therefore manpower at the observatory shall be minimized and shall be limited as far as possible to preventive maintenance tasks.

REQ 118 Maintenance work on the Laser System shall be limited to work at system level and to the possible extent to the exchange of modules (Line Replaceable Units, LRUs). LRUs are defined as units which can easily (i.e. without extensive calibration etc.) be exchanged at the telescope by on-site maintenance staff of trained technicians.

REQ 119 Following the maintenance strategy as defined by the Contractor, the LRUs will be repaired on site by trained personnel or at Contractor premises, on the basis of a support contract.

REQ 120 The Laser System opto-mechanical design shall secure that, when replacing LRUs, the output beam position and pointing are repeatable with the following accuracy:

- 100 µm RMS in X and Y directions (perpendicular to the optical axis).
- 0.16 mrad RMS tip and tilt.

REQ 121 It shall be possible to open and to hold the cover of the Laser Unit enclosure by at least 90 deg and without any hindrance.

REQ 122 A list of spares parts, required to meet the life time, operations and environmental requirements specified in REQ 115 and sections 4.5 and 4.6, shall be defined.

REQ 123 Standardization and modularity of the Laser System components are required and shall be considered in the design.

REQ 124 Maintenance involving the complete removal of Laser Units from the telescope shall be avoided to the greatest possible extent.

REQ 125 All special equipment and tools required for the Laser System maintenance (including LRU repair and test if required) shall be designed, manufactured, tested and delivered with the Laser System.

Two different categories of maintenance shall be considered:

- Preventive maintenance (including overhaul)
- Repair/corrective maintenance

During maintenance operations, the UT is parked pointing to the zenith.

4.9.2.2 Preventive maintenance

Preventive maintenance includes activities which are performed on a periodical pre-planned basis in order to prevent malfunctioning or unexpected downtimes of the Laser System. Typical preventive maintenance actions could be (to be defined by the supplier):

- Inspections;
- Renewal of consumables (e.g. pump diodes, crystals, coated optics, cleaning or exchange of filters);
- Functional check, e.g. of emergency stop buttons;
- Cleaning of optical surfaces.

Preventive maintenance tasks include the maintenance of performance. These may in particular concern (to be defined by the supplier):

- Global check of optical powers and throughput;
- Tuning of parameters;
- Check of optical alignments.

Overhauls are meant as preventive maintenance operations during which the equipment is not operational and telescope observing time is lost. Overhauls may involve removal of the complete Laser System or of the Laser Units from the telescope and partial or total disassembly.

REQ 126 Preventive maintenance actions of the Laser System shall be planned on a periodicity of:

- Every day 1 person-hour in total for a daily remote health check. As a goal, it shall be possible to include this daily health-check in the time required to bring the Laser Units in their operational mode.
- Every week 2 person-hours (goal 1 person-hour) in total for relatively simple inspections and actions.
- Every month 16 person-hours (goal 8 person-hours) in total for a thorough inspection, tests, computer maintenance and limited actions.

REQ 127 The preventive maintenance tasks of the Laser System shall be accomplished by two WMKO trained Technicians with a minimum of special equipment or tools.

REQ 128 The need for periodic overhauls will be determined case by case and as a general rule shall be avoided. If, however, overhauls appear necessary (e.g. as indicated by monitoring and/or test routines), they shall not require more than 40 person-hours (up to 3 observing nights) and shall not take place more often than every 2 years (goal 5 years) for the Laser System. Typical overhauls are change of an embedded component.

4.9.2.3 On-Site Repair /Corrective Maintenance

Replacement or repair takes place only in case of failure of the Laser System.

REQ 129 A LRU replacement shall be accomplished by a maximum of 2 trained technicians with a minimum of special equipment or tools in a maximum time of 4 hours, including restart of the Laser System and performance verification, excluding the time required to access the Laser System.

4.9.2.4 Monitoring & Test Software

REQ 130 The monitoring and test routines for the Laser System maintenance (see section 4.4.8) shall be defined. These shall be agreed upon in the design phase.

REQ 131 Self-test of the Laser System shall be executed at least when going from Stand-by Mode to On Mode and at other times at user request. It shall locate failure down to LRU level.

REQ 132 A list of all parameters to be monitored, allowing a detailed follow-up of the Laser System performance, shall be defined.

REQ 133 Monitored parameters shall be stored in the local database to be accessible from the control software.

4.9.3 Safety requirements

This section defines the safety requirements to preclude or limit hazards to personnel and equipment during the whole life cycle (assembly, disassembly, test, transport, storage, operation or maintenance and disposal) of the complete Laser System or parts thereof.

4.9.3.1 Hazard Risk Acceptance Criteria

REQ 134 During the development of the Laser System, the Hazard Risk Acceptance Criteria as defined in [KAD3] shall be used.

In section A.4.4.3.2.1 of [KAD3] Hazard Severity Categories are defined w.r.t. health and environment. The table below completes the definition of these categories for property damage.

Category	Description	Mishap Definition
I	CATASTROPHIC	System loss[1)]
II	CRITICAL	Major system damage[2)]
III	MARGINAL	Minor system damage[3)]
IV	NEGLIGIBLE	Less than minor system damage

[1)] System loss: the system cannot be recovered at reasonable costs.
[2)] Major system damage: the system can be recovered but extensive industrial support is necessary and/or the system is out of operation for more than 3 weeks
[3)] Minor system damage: the system can be repaired by WMKO without any support from industry and/or the system is less than 3 weeks out of operation

4.9.3.2 General Safety Requirements

REQ 135 The Laser System shall comply in all respects with the applicable requirements of the Occupational Safety and Health Administration (OSHA) as established by CFR 29 Part 1910 "Occupational Safety and Health Standards", particularly subpart O, section 1910.212 and subpart S sections 1910.302 through 1910.304.

Mechanical Safety

Structural elements and fasteners whose failure could cause injury to personnel or equipment must be selected for a safety factor of 10 over the ultimate strength of the material. All other structures and fasteners should be designed with a safety factor of at least 5.

The normal operation of the laser system must not produce any safety hazard to personnel or equipment. Interlocks, labeling and procedures must be provided to ensure the safety of personnel and equipment during maintenance and repair.

No part of any laser system mechanism shall move when ac mains power is applied to or removed from laser system. The laser system motion control hardware shall inhibit all motion during a power on/reset.

If closed loop or servo systems are used in the laser system motion control systems these servo loops shall be designed so that loss of the encoder signal or disconnection of the motor cannot result in a "wind up" of the servo position command. Software features shall be implemented to inhibit motion when the position error measured by the servo controller exceeds the smallest reasonable margin that reflects all of the expected operating conditions.

Limit switches shall be closed when not actuated (N.C. contacts). Motion control software shall be designed so that a disconnected limit switch will appear to be active, inhibiting further motion towards that limit. Motion control software shall also be designed so that movement away from an active limit switch is restricted to a reasonable distance past the limit switch actuation point after which motion is stopped and an error indicated due to the apparent failure of the limit switch to open.

If used, position encoders shall include a status loop through the connections to the encoder so that in the event of loss of the encoder connection (or intentional disconnection) all motion on the associated axis is inhibited.

Electrical Safety

The design and construction of the laser system shall conform to the requirements of UL Standard for Safety 508 "Industrial Control Equipment". The design and construction of the wiring of the laser system shall conform to the requirements of the National Electric Code. The applicable local electric code is the Hawaii County Code 1983, 1995 Edition. This code adopts the National Electric Code in its entirety and there are no additional special requirements applicable to the locations where the laser system will be installed or operated.

All ac line connected parts shall be fully enclosed so as to prevent accidental contact with live parts. All ac line connections shall utilize UL listed connectors and cables.

All power input connectors shall have an adjacent label indicating the voltage, frequency and current rating for which the equipment is designed.

A fuse or circuit breaker shall internally protect all ac line connected equipment. When a time delay fuse or time delay breaker is used the rating of the breaker shall not exceed 150% of the continuous full load current of the connected load. Where a non-time delay fuse is used the rating of the fuse shall not exceed 150% of the continuous full load current of the connected load. Where an instantaneous trip breaker is used the rating of the breaker shall not exceed 250% of the continuous full load current of the connected load.

The panel where the fuse or circuit breaker is located shall be clearly marked with the type and rating of the protective device.

Removable covers that permit access to circuits with voltages in excess of 36 volts rms ac or 30 Vdc shall be marked with a warning label.

Removable covers that permit access to circuits of less than 36 volts rms ac or 30 Vdc that are capable of fault currents in excess of 2 amperes shall be marked with a warning label.

Removable panels that expose voltages in excess of 230 Vac or 500 volts dc should be equipped with defeatable interlock switches that remove all voltages in excess of 36 volts ac or dc from all exposed connections and terminals.

Wiring

Internal wiring of 120/208/240 volts ac circuits shall use UL type AWM stranded wire with an insulation thickness of at least 0.8 mm. Where wiring is not subjected to movement or damage, any UL listed style including style 1371 (MIL-W-16878/4) suitable for the purpose may be employed. Where wiring may be subjected to movement, such as in service loops between internal subsystems, additional insulation shall be provided to protect the wire from damage. Teflon insulated wire shall be secured or tied in a manner that does not cause cold flow of the insulation.

The insulation color of internal wiring and the conductors of multi-conductor cable for AC power wiring shall conform to the requirements of the National Electric Code. The insulation of neutral (grounded) conductors shall be white or gray in color. Neutral conductors shall be the same size as phase conductors except in cases where two or more phases are provided and harmonic currents are expected, in which case the neutral conductors shall be 125% of the size of the phase conductors.

The insulation of grounding conductors (protective or earth ground) shall be green or green with a yellow stripe.

Grounding conductors shall be the same size as the phase conductors.

AC power phase, neutral and ground conductors shall be sized using table 310.17 of the National Electric Code for individual conductors used for internal wiring and table 310-16 for external connecting cables. For cables with more than three conductors used for AC power wiring the derating adjustment factors of table 310.15(B)(2)(a) shall be applied.

Terminations

Crimp terminals and compression screw terminals shall not be used to terminate more than the number of conductors specifically approved for the terminal. All crimp terminals and screw terminals used for AC line connected wiring must be UL recognized components. All crimp terminations shall be performed using the manufacturer's tooling in accord with the manufacturer's instructions.

Grounding

The enclosures of AC line connected components shall be grounded. Grounding conductors shall be continuous and bonded to the enclosure in at least one point.

The grounding point shall be specifically provided for the purpose and shall not be a screw or nut used for mounting components or covers. Any paint or surface treatment that acts as an insulator shall be removed in order to ensure a good electrical contact for the ground connection.

Altitude Derating

The voltage ratings of relays, switches and insulated cables must be reduced to 80% of their rated value due to the altitude at the summit of Mauna Kea. Electrical spacings must also be increased by a factor of 1.25 to compensate for the increased altitude.

The normal dielectric withstand test specification for UL approved or listed components for use in ac line connected equipment operating from 120/240 volts ac is 2500 volts AC/60 Hz for one minute. Voltage ratings for all components should be checked for safety margin with respect to this rating using the following equation:

$$VI = \frac{2 * V + 1000}{AF}$$

where :

VI is the voltage isolation required for the altitude

AF is the altitude factor of 0.8 for 15,000 feet

V is the sea level rated working voltage

The resulting value for VI must be less than the dielectric withstand test specification voltage (2500 volts AC) or a dielectric withstand test at altitude must be performed to ensure that the system is safe for the intended application.

REQ 136 Not Applicable.

4.9.3.3 Laser Safety

REQ 137 Laser safety features incorporated into the Laser System shall comply with the safety regulations for laser systems as defined in IEC 60825-1. In particular the following points are observed (summarised here as overview):

- The Laser Units have a protective housing which prevents human access in excess of the limits of Class I radiation.
- The Laser Units are key-controlled; the Laser Units cannot be turned on or operated until the key-switch is ON position.
- The Laser Units provide laser radiation emission indicators. The indicator light is seen through all necessary safety glasses.
- The Laser Unit covers are equipped with redundant safety interlocks (and interlock defeats be provided) which prevent the Laser Units from operation with the cover open.

- The Laser Units provide a remote interlock connector; its terminals must be connected for the Laser Units to operate.
- A laser output shutter is provided. The laser output shutter shall have the following characteristics:
    - The shutter shall be 100% opaque at all wavelengths present in the output beam and shall be able to remain closed for an indefinite amount of time. When the shutter is closed there shall not be any additional heat load presented to the ambient environment.
    - The laser shutter shall close in one second or less. Shutter opening include a software delay of 5 seconds as required for compliance with FDA laser safety requirements. The delay shall be adjustable.
    - The laser shutter shall be controlled both manually via hardware and remotely via software.
    - The laser shutters shall be held closed by a positive acting mechanical device and held open by an electrically energized device. In the event of a power failure the laser shutters shall close.
    - The laser shutters shall be equipped with position sensing switches (electro-mechanical or optical) that shall positively indicate the position of the shutter to the laser system control circuits for monitoring by the laser system software.
    - The laser system shall be equipped with a "laser shutter manual switch" located on the laser bench enclosure. This switch shall provide two positions: the "Disable" position shall keep the laser shutter closed and prevent opening of the laser shutter via software at all times. The "Enable" position shall enable normal laser shutter operation.
- The Laser Units shall be equipped with warning labels indicating removable protective housings and apertures through which laser radiation is emitted.
- All local controls are located in a such a way that the operator need not to be exposed to laser emission

4.9.3.4 Mechanical Safety

REQ 138 Not applicable (see REQ 135).

REQ 139 Transport, lifting, hoisting devices and similar equipment shall comply to the applicable EC directives and shall be approved by an officially recognized independent verification agency (TUVus or similar institution).

4.9.3.5 Emergency Braking

REQ 140 The Laser System shall be able to sustain an emergency braking event at any position of the telescope altitude axis (Altitude angle at which the braking may occur: -6.4º to 94.1º) with a maximum angular deceleration of:

- Around the telescope altitude axis: $10^{\circ}/s^2$.
- Around the telescope azimuth axis: $10^{\circ}/s^2$.

The deceleration may occur at any time on both axes, simultaneously.

4.9.3.6 Protection against electric shock and other hazards

REQ 141 Not applicable (see REQ 135).

REQ 142 Not applicable (see REQ 135).

4.9.3.7 Bond corrosion

REQ 143 To prevent bond corrosion, pairing of dissimilar metals shall be avoided.

REQ 144 Should joints between dissimilar metals be absolutely unavoidable, metals to be in direct contact shall exhibit the lowest possible combined electrochemical potential (in any case below 0.6V~~, according to [**Error! Reference source not found.**]~~) and the anodic member of the pair shall be the larger in size of the two.

4.9.3.8 Cooling System Safety

REQ 145 The cooling system shall be designed in accordance with the electrical safety requirements (see REQ 135). All Laser System cooling circuits connected to the main telescope cooling circuit shall be pressure tested at 10 bar for 30 minutes.

4.9.3.9 Software Safety

REQ 146 Any computer software failure or failures shall not lead to an unacceptable or undesirable hazard risk (see REQ 134).

REQ 147 Not applicable.

4.9.3.10 Handling, Transport and Storage Safety

REQ 148 The design of the Laser System shall incorporate all means necessary to preclude or limit hazards to personnel and equipment during its whole life cycle: assembly, disassembly, test, transport (including on site), short/long term storage and disposal.

4.9.3.11 Operational Safety

REQ 149 None of the following cases shall lead to an unacceptable or undesirable hazard risk for the Laser System, the telescope itself or human beings:

- One or two independent operator errors;
- One operator error plus one hardware failure;
- One or two hardware failures;
- Partial or complete loss of energy supplied to the Laser System;
- Emergency braking of the telescope altitude structure;
- MLE earthquakes happening for whatever position of the Laser System;
- Wind loads.
- Emergency shutdown as outlined in REQ 38.

REQ 150 The Laser System design shall avoid any liquid (for example cooling fluid) or any other material or object to fall onto the telescope mirrors during operation or maintenance activities.

REQ 151 If required for safety, the Laser System shall be able to deliver a global interlock signal to the LGSF (see section 4.4.6 for interface specifications).

REQ 152 The laser system shall have a 24 Vdc input for connection to the telescope or observatory emergency stop circuit. The laser system shall not be able to be placed in any mode other than Off unless this input is energized. When this input is de-energized the laser system shall immediately transition to the Off mode. Reset (re-energization) of the telescope or observatory emergency stop circuit must not cause the laser system to leave the Off mode.

REQ 153 A list of interlocks shall be defined, such as to operate and maintain safely the Laser System in the telescope context and such as to operate and maintain safely the telescope with the Laser System. This list shall be based on the outcome of a hazard analysis~~ according to **Error! Reference source not found.**~~.

REQ 154 The interlock design shall be based on the outcome of a hazard analysis ~~according to **Error! Reference source not found.**~~.

4.10 Transport, Integration, Installation, Service and Testing Requirements

4.10.1 General requirements

This section provides the requirements for:

- The packing of the Laser System;
- The transport from the Contractor premises to the Observatory Site or to WMKO headquarters;
- The unpacking at the Observatory Site or at WMKO headquarters;
- The re-integration at the Observatory Site or at WMKO headquarters;
- The testing of the Laser System in the Observatory Site or in WMKO headquarters.

REQ 155 The detailed procedures for all the phases defined above shall be defined depending on the design of the Laser System.

REQ 156 When packaged as required the Laser System shall continue to meet all of the performance requirements without repair after a single shipment to the delivery location by any combination of air or surface transportation. For information, the expected conditions to be encountered during shipping are given in Table 7.

Table 7: Transportation and Shipping Environment

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4,572	m	1

Temperature	-33	-	71	ºC	2, 3
Temperature shock	-54	-	70	ºC	4
Humidity	0	-	100	%	5
Gravity orientation	-	-	-	NA	6
Vibration	-	-	0.015	g^2/Hz	7, 8
Shock	-	-	15	g	9
Acceleration					
Due to transport	-	-	4	g	10
Due to seismic activity	-	-	2	g	12

Notes:

1. See MIL-STD-810F Method 500 §2.3.1.
2. Maximum is for induced conditions; see MIL-STD-810F Method 501 Table 501.4-I.
3. Minimum is for induced conditions; see MIL-STD-810F Method 502 Table 502.4-II.
4. See MIL-STD-810F Method 503.
5. Relative, condensing.
6. Packaged equipment may be subjected to all possible gravity orientations during transportation and shipping.
7. 10 Hz to 40 Hz, -6dB/oct. drop-off to 500 Hz, all axes.
8. See MIL-STD-810F Method 514.
9. 0.015 second half-sine, all axes.
10. All axes.
11. 0.5 Hz to 100Hz, all axes.

REQ 157 In case particular equipment will require more restrictive transport conditions from those defined in REQ 156 these conditions shall be clearly identified.

REQ 158 The Laser System can be transported from the Contractor premises to the observatory site or to WMKO headquarters either in one single assembly or in several sub-subassemblies.

REQ 159 The design of the Laser System shall take into account transport requirements and constraints and shall be based on the following principles:

- As a goal, to avoid oversize special transport.
- Use of standard containers for critical parts. Containers shall be dust- tight and water-tight.
- Redundancy in case of partial loss.

REQ 160 All components, which have to be handled as a single piece during transport, assembly or maintenance and whose weight is above 10 kg shall be provided with the necessary attachment points and tools for a safe manipulation.

4.10.2 Installation requirements

REQ 161 Any special tools and equipment necessary for packing/unpacking, handling, integration and testing of the Laser System shall be provided to allow the Laser System to be integrated and tested at the Observatory Site or in WMKO headquarters.

REQ 162 All hoisting equipment necessary for connection to the crane hook during the integration and handling of the Laser System or parts of it, covers and containers shall be defined and provided. The installation of the Laser System will be done with the telescope parked looking at zenith. The telescope crane payload is 5 tons ~~(see section 3.6.2 of [**Error! Reference source not found.**])~~.

REQ 163 The Laser System shall be protected during handling and installation.

REQ 164 It shall be possible to remove the protection at the end of the installation.

4.10.3 Shipping container

REQ 165 The shipping containers shall be defined to transport the Laser System as a single unit or in several sub-units.

REQ 166 All the necessary handling tools required during packing and unpacking of the Laser System or sub-units shall be defined.

REQ 167 All shipping containers must be designed to provide adequate protection for the equipment during transport. For guidance in the design of suitable containers consult Air Transport Association (ATA) Spec 300, 2001.1 edition, "Specification for Packaging of Airline Supplies".

REQ 168 Shipping containers shall be re-usable, for shipments back to the Contractor or storage.

REQ 169 Not applicable.

REQ 170 Protective covers of the Laser Units exit optics surface and of the holes of the mechanical assembly which give access to optical surfaces, if any, shall be provided and used during transport and handling.

REQ 171 The Laser Units, including auxiliary equipment, shall be cleaned before packing (for storage or transport, as appropriate) into their transport container. Emphasis is put on:

- Grease and lubricants;
- Corrosive, abrasive and polishing dust or powders;
- Dust on the optical surfaces.

5 REQUIREMENTS FOR DESIGN AND CONSTRUCTION

5.1 Measurement Units

REQ 172 The following units shall be used for the Laser System design and analysis, and in all documents and drawings:

- Time seconds (s), minutes (mn) and hours (h)
- Linear dimension millimetre (mm) and meters (m)
- Angular dimension degree (°), arcminute ('), arcsecond (") and radians (rad).
- Cross-section square millimetres; mm²
- Mass kilogram; kg
- Force Newton; N
- Torque Newton meter; Nm
- Stress Newton / square millimetre; N / mm²
- Temperature degrees Celsius; °C
- Wavefront data nm wavefront

5.2 Materials, Parts and Processes

REQ 173 All equipment, materials and components selected for the Laser System, except consumables, shall be suitable for continuous operation over the useful lifetime and with maintenance operations intervals specified in section 4.9.2 and under the operational environmental conditions referenced in section **Error! Reference source not found.**.

REQ 174 In particular, the selection of materials and equipment shall take into consideration the requirements for operation in dry conditions, at the altitude of the W.M. Keck Observatory (4200 m above sea level). The following material requirements apply:

Materials Suitability and Safety

Certain environmental conditions (low temperature and pressure) at the summit of Mauna Kea make certain materials unsuitable for use in laser system construction. Materials used in the construction, lubrication or packaging of the laser system must not produce hazardous by-products such as gases or other contaminants under the conditions of operation and use at the summit of Mauna Kea. No mercury may be used in any component of the laser system.

Table 8 lists specific materials that should not be used. Note that this table applies to portions of the laser system normally open to the atmosphere or in environments where they are subject to exposure to the summit ambient conditions during either operation or maintenance.

Table 8: Materials not suitable for use in equipment at the summit of Mauna Kea

Material Type	**Common Name**	**Reason(s) for Unsuitability**
Adhesive, insulator	RTV silicone rubber[1]	Outgases during curing
Adhesive	Cyanoacrylates	Outgases during curing, subject to hydrolytic degradation
Conductor	Mercury[2]	Reactive, salts formed are toxic
Insulator	Acrylic[4]	Outgases, hygroscopic, brittle at low temperatures
Plated finish	Cadmium[2]	Outgases, reactive, hazardous
Insulator	Cellulose Acetate Butyrate	Hygroscopic
Insulator	Glass-Reinforced Extruded Nylon	Outgases, hygroscopic
Insulator	Kapton	Subject to hydrolytic degradation
Insulator	Neoprene	Outgases, subject to degradation by ozone and UV exposure
Insulator	Nylon[5]	Outgases, subject to degradation by ozone and UV exposure
Insulator	Phenolic[3]	Hygroscopic
Insulator	Polychlorinated Biphenyls[2]	Combustion produces highly toxic gases

Notes:

1. Neutral cure RTV silicones may be acceptable provided that the cured silicone and the surrounding area are cleaned after assembly
2. Use is or soon will be highly regulated
3. Electrical grade phenolic is not hygroscopic

4. Cast acrylic resin
5. Cable ties of weather resistant Nylon 6/6 (carbon black additive) are acceptable

Where elastomeric components and flexible tubing are required, such materials shall be selected from materials that are resistant to elevated ozone levels and prolonged low relative humidity.

Lubricants must be selected from materials that function, with minimum outgassing, at low temperatures appropriate for the environments listed in section 4.5.

Fasteners

Press fit studs or threaded inserts must be installed in the correct material according to the manufacturer's instructions. Self tapping screws shall not be used for removable covers or to secure components that will have to be removed for repair or replacement.

With the exception of COTS components and subsystems, fasteners shall have either Phillips or hex socket heads. Hex socket button head fasteners should not be used except where space or specific function requires them. Undercut flathead machine screws should not be used except in special cases where there is no other appropriate design alternative.

With the exception of COTS components or subsystems, fasteners shall be locked when necessary or appropriate. Prevailing torque locknuts or lock washers are preferred over thread locking compounds. Soft insert locknuts should have Kel-F or Vespel inserts, and should only be used where subsequent removal is not anticipated.

Service Access

Components requiring routine service or maintenance should be accessible by removing a single cover secured by no more than 8 fasteners.

Covers that may be removed in a location where fasteners could fall into the interior of the enclosure shall be equipped with captive fasteners. Captive fasteners shall be of the threaded type and not captivated by swaged sleeve fittings. Quarter turn fasteners engaging spring hooks are specifically discouraged for reasons of fit and reliability.

Whenever possible service access provisions should be provided that do not require disassembly of the entire system or subsystem to access motors or switches for replacement.

Enclosures

Enclosures shall be designed so as to prevent dust from entering the enclosure.

Enclosures shall be designed so as to prevent condensation inside the enclosure.

Over temperature protection shall be provided in all laser system enclosures to protect the components from damage due to over heating due to a coolant supply failure. Unless otherwise specified over temperature protection shall be accomplished by a thermal cut off device that removes all power from the components in the enclosure where the over temperature occurs. Reset of the thermal cutoff device will restore power to the laser system but restart of the laser system will require manual intervention.

The Laser System enclosure must meet the requirements of a NEMA type 4 or better enclosure. The requirements for NEMA type 4 enclosures are given in the National Electric Manufacturers Association (NEMA) standards publication 250-1997, "Enclosures for Electrical Equipment (1000 Volts Maximum)".

REQ 175 In particular, design of clearances and creepage distances shall adopt the altitude correction factor pertaining to the altitude of the W.M. Keck Observatory.

REQ 176 In order not to introduce vibrations into the telescope the Laser Units shall not use rotating motors or other vibrations generating equipment e.g. for alignment purposes when in Observation Mode (see section 4.6.4). When not in Observation Mode, this type of components can be used in functions which are operated occasionally.

5.3 Surface Treatment on Mechanics

REQ 177 The surfaces of the Laser System shall be protected according to the following requirements:

- All parts shall be corrosion-protected according to DIN 55928-TO5. External steel surfaces shall be painted with epoxy paint;
- All painted parts system shall be suitable for protection of the structure for 10 years;
- Machined interface surfaces, such as bolted joints and flanges, shall be protected according to DIN 55928-T05, chapter 3.1;
- To reduce reflections, all surfaces surrounding the Laser System optical path shall have a mat black surface treatment suitable for the type of material

concerned (except for where high power light may be encountered during test or maintenance);

- The colour of the outer surfaces will be defined together with WMKO in the design phase. They shall be painted.
- According the IEC60529 the Laser System shall have IP20 certification for equipment that will be installed inside protected cabinets (IP55). Equipment installed outside cabinet or equivalent enclosure shall have IP65 certification.

5.4 Software

The following requirements assume the Laser Control Software is a stand-alone system interfacing to a WMKO Local Control Unit. In this case, the WMKO LCU is WMKO responsibility.

~~The requirements for the two cases are given below.~~

5.4.1 Case 1: Requirements for the Laser Control SW embedded in a LCU

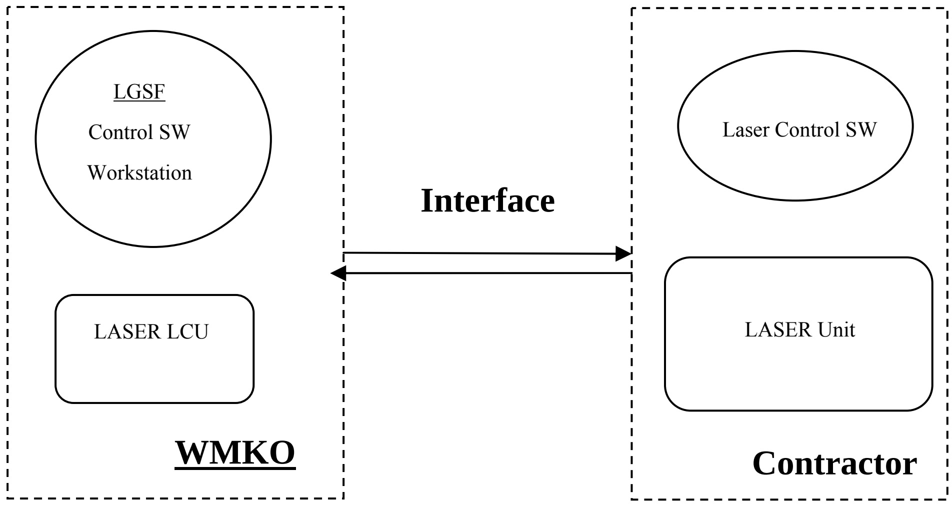
In this case the Laser Control SW run within a WMKO LCU and the installed boards directly steer the Laser devices.

REQ 178 Not applicable.
REQ 179 Not applicable.

5.4.2 Case 2: Requirements for a Stand-Alone Laser Control SW

In this case the Laser Control SW is seen as a “black box” and its compliance to the WMKO standard is defined through its interface to the WMKO control system.

The following sketch illustrates the software and hardware architecture between the WMKO LGSF and Laser System. This architecture describes each Laser Unit and allows their individual control. The interface is specified in Section 4.4.3.



REQ 180 The following list describes the requirements that shall be fulfilled by the external software.

- The SW interface shall support VxWorks or Linux operating systems.
- The SW interface to the WMKO HW/SW shall be defined in agreement with WMKO through an ICD and not subject to further changes after PDR. The ICD shall be defined in the early time of the Preliminary Design Phase, and shall contain at least:
  - Definition of system and functional tests.
  - Specification of the test and maintenance tools used to verify the SW reliability.
  - Specification of the test tools used to verify the SW functionality. They shall be also used during the acceptance procedure.
  - Specification of the maintenance and debugging tools that shall be integrated in the WMKO control SW.
  - Specification of the SW tools used to support the tuning of the Laser System performance.
- The proper documentation of the critical control algorithms shall be delivered.

5.4.3 Common Requirements

The following requirements are applicable to any laser control SW architecture.

REQ 181 The SW should provide access to all information defined in REQ 44, REQ 48 and REQ 49.

REQ 182 Optional. The Laser System software shall include a simulation mode that can be invoked for each for the Laser Unit as long as that Laser Unit is present. While in simulation mode, the Laser System software shall accept commands and queries from the WMKO LGSF control software and shall respond and react in a realistic dynamical way (i.e. including delays). The simulation mode will be used to test the software interfaces between the WMKO LGSF and the Laser System as a whole, without requiring that the Laser Unit under test produces an actual laser output or other physical changes to its operating state.

REQ 183 The Laser System shall be controlled by the WMKO LGSF.

REQ 184 The Laser Control software shall implement the following states:

a. OFF: part of the software is not running and part or all of the software is not running, and devices can be powered off.7

b. STANDBY: the software and hardware interfaces are initialized; part of the hardware can be not initialized.

i. Lasers are off

ii. Shutters are closed

iii. Encoders are on (if applicable)

iv. Motors current is off (if applicable)

v. Sensors monitoring is active

c. ON-LINE: all software and hardware is loaded, initialized and active. This is the normal state during operation.

REQ 185 COTS solutions shall be used whenever available. All COTS and third party components and subassemblies supplied as part of the laser system shall be UL recognized or bear a UL or CE mark.

REQ 186 Special custom solutions, using technology with limited lifetime, shall be avoided wherever possible.

REQ 187 Final choices of technology shall be made in agreement with WMKO.

5.5 Electrical and electronics requirements

REQ 188 As a goal, electric and electronic components of the Laser System shall preferably use WMKO standard HW. The following requirements apply:

All wire and cable shall be rated for an ambient temperature range of –30 °C to 100 °C.

Grounding and shielding shall conform to the applicable requirements (fixed ground equipment) sections of MIL-STD-464A “Electromagnetic Environmental Effects, Requirements for Systems”. The laser system shall in particular meet the requirements of 5.10 and 5.11. The laser system shall be tested for ground integrity and tested to ensure that the bonding resistance limit for Class H for shock hazard (0.1 ohm) as described in Appendix section

A5.10 is met by all laser system grounds and enclosures including doors and covers.

All components capable of generating electromagnetic emissions in excess of the limits established in the standards referenced in section 5.6 shall be shielded and the shielding grounded to limit electromagnetic emissions to the levels allowed by the standards referenced in section 5.6. All components susceptible to externally generated electromagnetic emissions in excess of the limits established in the standards referenced in section 5.6 shall be shielded and the shielding grounded to protect those components from unintended operation due to external electromagnetic emissions of the levels established in the standards referenced in section 5.6.

Cable shields shall be terminated to the connector housings and not via a wire to a connector pin. Where it may be necessary to isolate shields due to common mode noise problems, cable shield terminations shall be made at one end of the cable only, with the end selected for termination being the one that is closest to the point in the system where the zero signal reference potential is grounded. This is normally the location of the terminating load resistance for signal inputs and the location of the signal source for outputs.

Cable shields shall be electrically continuous with the connector housing, and WMKO requires that no ground pigtails or other wire connections separate from the connector housing be used. In cases where the design requires different practices those design requirements must be reviewed with WMKO prior to implementation.

Where multiple connector pairs of identical type are used each connector pair should be uniquely keyed to prevent accidental interchange of the connections.

All connectors should include pre-grounding pins that make circuit common connections (dc reference or ac protective ground) before all other connections during connector insertion and break circuit common connections (dc reference or ac protective ground) after all other connections during connector removal.

Connectors used for low voltage ac and dc circuits shall conform to military specification MIL-C-38999 series IV.

Cables and wiring shall be routed so that they do not interfere with the optical path of the laser system. Cables and wiring must be routed so that full travel of moving or adjustable parts is not affected and does not place a strain on the mounting or connections of any cables or wiring. Service loops shall be provided when necessary, but all cables shall be routed neatly and secured at regular intervals with wire ties or lacing cord.

All removable modules shall be equipped with positive retention features. Extraction handles shall be provided for all connectorized plug-in modules.

Access to electronic modules and cabling shall be designed to facilitate in situ monitoring of electronic performance, troubleshooting and module replacement. Clearly labeled test points shall be provided for signals and voltages useful for module testing and fault diagnosis. Some critical test points will be accessible without disassembly of the module or removal of the module from the system, as needed.

All electronic modules shall be capable of being repaired or, alternatively, replaced, without removing the laser system from its installed location.

The laser system shall be designed so that all subsystems and components are supplied with power from either the laser system AC mains power input with suitable internal distribution and protection, or from a 120 Vac or 208 Vac input power conversion system (such as a DC output power supply) supplied from the AC mains power input via suitable internal distribution and protection. Except for configuration memory or real time clock back-up in computer systems or operating hours meters, no batteries of any kind, rechargeable or otherwise, shall be used in the laser system.

All wire and cable shall be rated for an ambient temperature range of –30 °C to 100 °C.

Grounding and shielding shall conform to the applicable requirements (fixed ground equipment) sections of MIL-STD-464A “Electromagnetic Environmental Effects, Requirements for Systems”. The laser system shall in particular meet the requirements of 5.10 and 5.11. The laser system shall be tested for ground integrity and tested to ensure that the bonding resistance limit for Class H for shock hazard (0.1 ohm) as described in Appendix section A5.10 is met by all laser system grounds and enclosures including doors and covers.

All components capable of generating electromagnetic emissions in excess of the limits established in the standards referenced in section 5.6 shall be shielded and the shielding grounded to limit electromagnetic emissions to the levels allowed by the standards referenced in section 5.6. All components susceptible to externally generated electromagnetic emissions in excess of the limits established in the standards referenced in section 5.6 shall be shielded and the shielding grounded to protect those components from unintended operation due to external electromagnetic emissions of the levels established in the standards referenced in section 5.6.

Cable shields shall be terminated to the connector housings and not via a wire to a connector pin. Where it may be necessary to isolate shields due to common mode noise problems, cable shield terminations shall be made at one end of the cable only, with the end selected for termination being the one that is closest to the point in the system where the zero signal reference potential is grounded. This is normally the location of the terminating load resistance for signal inputs and the location of the signal source for outputs.

Cable shields shall be electrically continuous with the connector housing, and WMKO requires that no ground pigtails or other wire connections separate from the connector housing be used. In cases where the design requires different practices those design requirements must be reviewed with WMKO prior to implementation.

Where multiple connector pairs of identical type are used each connector pair should be uniquely keyed to prevent accidental interchange of the connections.

All connectors should include pre-grounding pins that make circuit common connections (dc reference or ac protective ground) before all other connections during connector insertion and break circuit common connections (dc reference or ac protective ground) after all other connections during connector removal.

Connectors used for low voltage ac and dc circuits shall conform to military specification MIL-C-38999 series IV.

Cables and wiring shall be routed so that they do not interfere with the optical path of the laser system. Cables and wiring must be routed so that full travel of moving or adjustable parts is not affected and does not place a strain on the mounting or connections of any cables or wiring. Service loops shall be provided when necessary, but all cables shall be routed neatly and secured at regular intervals with wire ties or lacing cord.

All removable modules shall be equipped with positive retention features. Extraction handles shall be provided for all connectorized plug-in modules.

Access to electronic modules and cabling shall be designed to facilitate in situ monitoring of electronic performance, troubleshooting and module replacement. Clearly labeled test points shall be provided for signals and voltages useful for module testing and fault diagnosis. Some critical test points will be accessible without disassembly of the module or removal of the module from the system, as needed.

All electronic modules shall be capable of being repaired or, alternatively, replaced, without removing the laser system from its installed location.

The laser system shall be designed so that all subsystems and components are supplied with power from either the laser system AC mains power input with suitable internal distribution and protection, or from a 120 Vac or 208 Vac input power conversion system (such as a DC output power supply) supplied from the AC mains power input via suitable internal distribution and protection. Except for configuration memory or real time clock back-up in computer systems or operating hours meters, no batteries of any kind, rechargeable or otherwise, shall be used in the laser system.

REQ 189 The design of custom electronics shall be part of design reviews before being implemented.

5.6 Electromagnetic Compatibility

REQ 190 The Laser System shall meet the conducted and radiated emissions limits for unintentional radiators as specified in Title 47 CFR Part 15, sections 15.107 and 15.109 for class B devices. The WMKO laser systems shall meet the electromagnetic immunity requirements given in the European Commission Directive 2004/108/EC, and the reference standard of the European Committee for Electrotechnical Standardization (CENELEC) EN 61000-6-1:2001 "Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments".

REQ 191 Not applicable.

5.7 Light tightness

REQ 192 Light sources of any equipment of the Laser System but the Laser Heads themselves (panel display, lamps, LEDs, etc.) shall be optionally switched-off or hidden during operational condition to prevent generation of stray light.

5.8 Cables and piping connectors

REQ 193 For reasons of dismounting from the telescope all cables and pipes going to and coming from the Laser System and the external electronic cabinets shall be equipped with quick dismounting connectors.

REQ 194 The fluid connectors shall be self sealing (see section 4.4.7).

5.9 Name Plates and product marking

REQ 195 The Laser System and Auxiliary Equipment shall be labelled or engraved with nameplates visible after installation of said Laser System or Equipment. The labels shall contain as a minimum the following information, as per Product Breakdown (see REQ 6):

- Assembly / component name and sequential number wherever applicable
- Manufacturing month and year
- Name and/or logo of manufacturer
- ~~ESO logo~~
- Labels to guide disassembly or handling, if deemed necessary

REQ 196 All name plates and indication labels shall be permanently marked, made of metal or laminated plastic, and be attached to the Laser System by means of screws or rivets.

REQ 197 All dismountable parts, except standard parts like screws or washers, shall be marked or equipped with identification labels. The markings and identification plates shall be visible after installation and shall contain the following information:

a) Custom manufactured parts, or modified purchased parts:
   - Part/assembly number which shall include the product code number
   - Drawing number including revision
   - Manufacturing month and year

b) Purchased parts:
   - Name and address of manufacturer
   - Part number/Serial number
   - Manufacturing month and year

REQ 198 All external, interconnecting cables shall be uniquely identified and labeled. The labeling and identification shall be in a clearly visible and non-removable form. This identification scheme shall be identical to that used in the system documentation. Identification of cables by color-coding is appropriate and encouraged but is not a substitute for clear labeling.

5.10 Workmanship

REQ 199 The methods and procedures used by the Contractor to develop and manufacture the Laser System shall reflect the state of the art in the respective fields of laser design, mechanical design, electrical and electronic design, development, manufacturing, alignment and testing. Machined components should be free of tool marks, scratches and material flaws such as inclusions or voids. All burrs and sharp edges shall be removed from all fabricated components unless the function of the component requires a sharp edge.

6 PRODUCT ASSURANCE AND VERIFICATION REQUIREMENTS

6.1 Analysis or simulation requirements

6.1.1 Laser simulation tools

REQ 200 The Laser System performance under the load cases defined in 4.8.3 shall be predicted by coupling a laser simulation tool to Finite Element Modelling tools.

REQ 201 As a goal, all the laser simulations used to predict the performance of the Laser System shall be performed with an internationally recognized numerical code. In case this tool is home-made, evidence of its validity and accuracy shall be provided.

6.1.2 Finite Element Structural Analysis

REQ 202 All the Finite Element Analyses necessary for the verification of the performance of the Laser System shall be performed with an internationally recognized numerical code.

REQ 203 The structural models used shall provide a good description of the behaviour of the structure under examination in terms of displacements, stress and frequencies.

REQ 204 The analysis errors due to mesh sampling shall be ≤10% in terms of FE internal criteria like the "Percentage error in energy norm". Alternatively this type of error shall be evaluated by mesh refining.

REQ 205 Special care shall be exerted to correctly apply the fixed boundary conditions and accurately simulate the interfaces between the mechanical components.

REQ 206 The result of the Operational load case (REQ 110) and the OBE load case (REQ 111) shall be evaluated to verify the operational performance of the Laser System.

REQ 207 The result of the Thermal Survival load case (REQ 112) and of the MLE load case (REQ 113) shall be evaluated to verify the survival of the Laser System.

REQ 208 For the purpose of investigating the effect of earthquake, the instructions described in [**Error! Reference source not found.**] shall be followed.

REQ 209 For the purpose of investigating dynamic cross-coupling effects, the Laser System shall be attached to the Telescope main Structure FE model delivered by ESO.

REQ 210 All the analyses listed and specified here below shall be performed. In case during the design phase it appears that other analyses are necessary in addition of the ones here specified, the list below shall not be considered exhaustive.

6.1.2.1 Gravity Load analysis

REQ 211 The effect of gravity shall be taken into account by means of FE analysis and laser simulations.

6.1.2.2 Thermal Deflection and stress analysis

REQ 212 The effect of non-uniform thermal displacement in the Laser Heads and their support system shall be taken into account by means of FE analysis and laser simulation.

REQ 213 The thermal analysis shall take into account the effects of the environmental thermal conditions both for the nominal operational range and the functional range as specified in section **Error! Reference source not found.**.

6.1.2.3 Modal Analysis

REQ 214 A modal analysis shall be performed to obtain accurate information concerning the Eigen frequencies of the Laser System.

6.1.3 Thermal Analysis

REQ 215 A thermal analysis shall be performed to verify that the design of the Laser System meets the requirement included in sections 4.5.

REQ 216 The thermal analysis shall take into account the effect of conductive, convective and radiative heat exchange.

REQ 217 The thermal analysis shall furthermore take into account the effect of temperature variations as specified in section 4.5. It shall include all identified heat sources.

REQ 218 The thermal analysis shall cover as a minimum:

- The Stand-by mode
- The On mode
- The Observation mode.

REQ 219 The analysis shall deliver as a minimum output:

- The thermal behaviour of the external surfaces of the Laser System.
- The cooling power required

6.2 Quality Assurance Requirements

REQ 220 For quality assurance management, DIN-EN-ISO 9001-2000, ECSS standards or similar standard shall be applied (~~see **Error! Reference source not found.** for reference~~).

6.3 Verification Matrix

6.3.1 General

REQ 221 The following methods of verification shall be applied to demonstrate that the performance requirements of the Laser System are met

- Verification by design: The performance shall be demonstrated by a proper design, which will be demonstrated to WMKO during the design phase of the contract by review of the design documentation.
- Verification by analysis: The fulfilment of the specified performance shall be demonstrated by appropriate analysis (calculations, finite element analysis, thermal modelling, etc.), which will be demonstrated to WMKO during the design phase.
- Verification by test: The compliance of the developed item / assembly / subassembly with the specified performance shall be demonstrated by

tests. WMKO reserves the right to witness any verification test. The error budget of the test setups shall be documented.

- Verification by inspection: The compliance of the manufactured hardware with the design documentation shall be demonstrated by in-manufacturing and end item inspections. WMKO reserves the right to witness any verification inspection.

REQ 222 All verification activities shall be properly planned, performed and documented. Tests shall follow a test plan and step-by-step procedures. The test plan shall define the necessary tests to be performed to demonstrate that the Laser System fulfils the requirements specified in this document

REQ 223 The Laser System shall be tested in the temperature range specified in section **Error! Reference source not found.**

REQ 224 The Laser System shall be tested under gravity load specified in section 4.5

6.3.2 Performance Verification Matrix

In the following table, the verification method is defined using labels D(esign), A(nalysis), T(est) and I(nspection). The labels P, F or Acc define when the performance will have to be verified:

- P: verification at the end of the Preliminary Design Phase
- F: verification at the end of the Final Design Phase
- Acc: verification during Acceptance Process.

Reference	Description	Verification method			
		D	A	T	I
REQ 1	The Laser System is made of 1, 2 or 4 Laser Units	P			Acc
REQ 2	One laser beam shall be delivered per LTS	P			Acc
REQ 3	N/A				
REQ 4	The laser beam as to be delivered as a free-space beam or via fibers	P			Acc
REQ 5	N/A				
REQ 6	Establishment of a detailed Product Breakdown		P/F		
REQ 7	The Laser System shall be designed following one of the four options	P			Acc
REQ 8	Allowed design volume for Option 1	P/F			Acc
REQ 9	Allowed design volume for Option 2	P/F			Acc
REQ 10	N/A				
REQ 11	Allowed design volume for Option 4	P/F			Acc
REQ 12	Maximum allowed mass		P/F	Acc	

Reference	Description	Verification method			
		D	A	T	I
REQ 13	Centre of Gravity position		P/F		
REQ 14	Non UPS electrical power available		P/F	Acc	
REQ 15	UPS electrical power available		P/F	Acc	
REQ 16	Power distribution connectors	F			Acc
REQ 17	Control interface	P/F			
REQ 18	N/A				
REQ 19	N/A				
REQ 20	Ethernet interface	P/F			
REQ 21	Control signals to be added for robustness	P/F		Acc	
REQ 22	N/A				
REQ 23	N/A				
REQ 24	N/A				
REQ 25	N/A				
REQ 26	N/A				
REQ 27	N/A				
REQ 28	Digital signals will consist in two lines	P/F			
REQ 29	Electrical connection between the two lines	P/F			Acc
REQ 30	Equivalent circuit for an output stage	P/F		Acc	
REQ 31	Input stage voltage	P/F		Acc	
REQ 32	Input stage current for a logic level of 1	P/F		Acc	
REQ 33	Digital signal insulation	P/F			
REQ 34	Digital signals connectors	F			Acc
REQ 35	Safety digital IO design	P/F			
Error! Reference source not found.	Safety digital IO signals mechanically connected	P/F			Acc
REQ 37	Safety interface shall use components and architecture of the appropriate SIL	P	F		
REQ 38	Minimum list of safety interface signals	P/F		Acc	
REQ 39	Standard coolant specifications delivered at UT4	P/F		Acc	
REQ 40	Liquid-liquid heat exchanger location	P/F			Acc
Error! Reference	Swagelok components for the cooling system	P/F			Acc

Reference	Description	Verification method			
		D	A	T	I
source not found.					
REQ 42	N/A				
REQ 43	Onset of corrosion to be avoided by design	P	F		
REQ 44	Control system design and functional requirements	P/F		Acc	
REQ 45	Control system interfaces	P/F		Acc	
REQ 46	List of control functions to be defined by the Contractor	P/F		Acc	
REQ 47	List of parameters to be monitored to be defined by the Contractor	P/F		Acc	
REQ 48	Monitoring of D_{2a} and D_{2b} lines	P/F		Acc	
REQ 49	Laser System maintenance and service software	P/F		Acc	
REQ 50	Collimated beam waist diameter		P/F	Acc	
REQ 51	Beam waist location		P/F	Acc	
REQ 52	Laser beam position stability		P/F	Acc	
REQ 53	N/A				
REQ 54	N/A				
REQ 55	Operational environmental conditions: outside the LCR		P/F	Acc	
REQ 56	N/A				
REQ 57	Functional environmental conditions: outside the LCR		P/F	Acc	
REQ 58	N/A				
REQ 59	Time required to put back the Laser System in operation after the occurrence of survival conditions		F	Acc	
REQ 60	The Laser System shall include five operational modes	P		Acc	
REQ 61	Definition of the state of the Laser System for the five operational modes		F		
REQ 62	Definition of all allowed transition steps and intermediate states		F		
REQ 63	Off Mode definition	P			
REQ 64	Telescope motion during Off Mode	F			
REQ 65	Environmental conditions during Off Mode	F	F		
REQ 66	Stand-by Mode definition	P			

Reference	Description	Verification method			
		D	A	T	I
REQ 67	Telescope motion during Stand-by Mode	F			
REQ 68	Environmental conditions during Stand-by Mode	F	F		
REQ 69	Time required for going from Stand-by to On Mode	F		Acc	
REQ 70	On Mode definition	P			
REQ 71	Telescope motion during On Mode	F			
REQ 72	Environmental conditions during On Mode	F	F		
REQ 73	Time required for going from On to Observation Mode	F		Acc	
REQ 74	Possibility to run a self test in On-Mode	P		Acc	
REQ 75	Observation Mode definition	P			
REQ 76	Telescope motion during Observation Mode	F			
REQ 77	Environmental conditions during Observation Mode	F	F		
REQ 78	Maintenance Mode definition	P			
REQ 79	All requirements fulfilled at the output of each beam of the Laser Units		P/F	Acc	
REQ 80	CW or QCW laser	P			
REQ 81	Output emission wavelength and accuracy		P/F	Acc	
REQ 82	Laser Line width		P/F	Acc	
REQ 83	Output power		P/F	Acc	
REQ 84	Fraction of output power in Na D_{2b} line.		P/F	Acc	
REQ 85	D_{2a}/D_{2b} Laser Units spectral properties		P/F	Acc	
REQ 86	Power percentages in line		P/F	Acc	
REQ 87					
REQ 88	Long term power stability		P/F	Acc	
REQ 89	Intensity noise		P/F	Acc	
REQ 90	Laser beam optical quality		P/F	Acc	
REQ 91	Output beam asymmetry		P/F	Acc	
REQ 92	Polarization of the laser beam	P		Acc	
REQ 93	Polarization direction	F		Acc	
REQ 94	Polarization direction stability		P/F	Acc	
REQ 95	To toggle on and off the Na D_2 line	P/F		Acc	
REQ 96	Robustness to back reflected optical power	P/F		Acc	
REQ 97	Residual output pump power level		P/F	Acc	

Reference	Description	Verification method			
		D	A	T	I
REQ 98	Eigen frequencies		F		
REQ 99	Temperature of the external surface of the Laser Units housing		F	Acc	
Error! Reference source not found.	Material used for thermal insulation shall be fire retardant	F			
REQ 101	No rotating equipments used for cooling purposes, or damping device design approval by ESO	P/F			Acc
REQ 102	Laser Units components shall be conductively water-cooled	P/F			Acc
REQ 103	The Laser System shall be remotely operated	P		Acc	
REQ 104	Possibility to operate the Lasers Units locally, without any computer	P		Acc	
REQ 105	Operation with azimuth angular acceleration		P/F		
REQ 106	Operation with altitude angular acceleration		P/F		
REQ 107	Operation with azimuth angular velocity		P/F		
REQ 108	Operation with altitude angular velocity		P/F		
REQ 109	Operation under gravity load variations		P/F		
REQ 110	Operational load case definition		P/F		
REQ 111	Operational Base Earthquake load case definition		P/F		
REQ 112	Thermal survival load case definition		P/F		
REQ 113	Maximum Likely Earthquake load case definition		P/F		
REQ 114	Operational vibration definition		P/F		
REQ 115	Laser System lifetime		P/F		
REQ 116	Laser System MTBF		P/F		
REQ 117	Maintenance work load to be minimized		F		
REQ 118	Maintenance work limited to LRU exchange		F		
REQ 119	LRU repair policy and support contract		F		
REQ 120	Output beam position and pointing stability after a LRU exchange		F	Acc	
REQ 121	Opening of the cover of the Laser Unit enclosure	P		Acc	
REQ 122	Spare Part List definition		F		
REQ 123	Standardization and modularity of the Laser System design	P			Acc

Reference	Description	Verification method			
		D	A	T	I
REQ 124	To avoid maintenance requiring to remove Laser Units from the telescope	F			
REQ 125	Maintenance equipment design, manufacturing and test	F		Acc	
REQ 126	Preventive maintenance periodicity	F			
REQ 127	Personnel and tools required for preventive maintenance	F		Acc	
REQ 128	Overhaul periodicity and associated resources	F			
REQ 129	Resources required to exchange a LRU	F		Acc	
REQ 130	Monitoring and test routines	F			
REQ 131	Self test of the Laser System	P/F		Acc	
REQ 132	List of parameters to be monitored	P/F			
REQ 133	Monitored parameters storage	F			
REQ 134	Definition of the Hazard Risk Acceptance Criteria	P/F			
REQ 135	Compliance of the Laser System components and equipments with their EN standards	P/F			Acc
REQ 136	N/A				
REQ 137	Compliance of the Laser System safety design with Laser Safety regulations	P/F			
REQ 138	N/A				
REQ 139	Transport, lifting and hoisting devices shall be certified				Acc
REQ 140	The Laser System shall sustain emergency braking		P/F		
REQ 141	N/A				
REQ 142	N/A				
REQ 143	Pairing of dissimilar metals shall be avoided	P/F			
REQ 144	To minimize combined electrochemical potentials	P/F			
REQ 145	Cooling system safety	P/F			
REQ 146	Software failure(s) shall not lead to unacceptable or undesirable hazard risks	F			
REQ 147	N/A				
REQ 148	Handling, transport and storage safety	P/F			Acc
REQ 149	Operational safety	P/F			
REQ 150	Laser System design shall avoid any liquid or material to fall on the telescope during operation or maintenance activities	P/F			

Reference	Description	Verification method			
		D	A	T	I
REQ 151	If required, the Laser System shall be able to deliver an interlock signal to the 4LGSF	P/F		Acc	
Error! Reference source not found.	If required, the Laser System shall be able to receive an interlock signal	P/F		Acc	
REQ 153	List of interlocks	P/F			
REQ 154	The interlock design shall be based on a Hazard Analysis		F		
REQ 155	Detailed procedure associated to packing, transport, unpacking, reintegration and test.	F			
Error! Reference source not found.	Definition of transport environmental conditions	P/F	F		
REQ 157	Restrictive transport conditions to be defined	F			
REQ 158	Transport from Contractor premises to ESO locations	F			
REQ 159	The Laser System design shall consider transport constraints	P/F			
REQ 160	Handling of components whose weight exceeds 10 kg	F			Acc
REQ 161	Integration, packing and test tools shall be provided				Acc
REQ 162	Hoisting equipment shall be defined and provided	F			Acc
REQ 163	Protection of the Laser System during handling and installation	F			Acc
REQ 164	Protection removal at the end of the installation	F			
REQ 165	Shipping containers to be defined	F			
REQ 166	Handling tools required for packing and unpacking to be defined	F			
Error! Reference source not found.	Shipping containers designed for sea, air and road conditions	F	F		
REQ 168	Shipping containers shall be re-usable	F			Acc
REQ 169	Double crate packing	F			Acc

Reference	Description	Verification method			
		D	A	T	I
REQ 170	Protection of Laser Units exit holes and surfaces	F			Acc
REQ 171	Cleaning of Laser Units before packing		F		Acc
REQ 172	Measurement Units	P/F	P/F		
REQ 173	Materials and components compliant with the Laser System lifetime and maintenance plan	F			
REQ 174	Materials and components compliant with Paranal Observatory environmental conditions	P/F	P/F		
REQ 175	Design clearance and creepage distances	P/F			
REQ 176	Rotating equipment like motors are not allowed for alignment purposes during Observation Mode	P/F			Acc
REQ 177	Surface protection/treatment	F			Acc
REQ 178	N/A				
REQ 179	N/A				
REQ 180	Compliance with embedded software interfaces with WMKO Software	P/F		Acc	
REQ 181	Compliance with interface requirements	P/F		Acc	
REQ 182	Simulation mode in software	P/F		Acc	
REQ 183	Laser control through 4LGSF control software	P/F		Acc	
REQ 184	Implementation of software modes	P/F		Acc	
REQ 185	COTS solution shall be used	P/F			
REQ 186	Special custom solutions shall be avoided	P/F			
REQ 187	Final technology choices shall be made in agreement with WMKO	P/F			
REQ 188	As a goal, electric and electronics components shall use WMKO VLT standard HW	P/F			
REQ 189	Custom electronics design shall be part of design reviews	P/F			
REQ 190	The Laser System shall be able to operate under electromagnetic environment		F	Acc	
REQ 191	N/A				
REQ 192	Light tightness	F			Acc
REQ 193	Cables and pipes shall be equipped with quick dismounting connectors	P/F			Acc
REQ 194	Fluid connectors shall be self sealing	P/F		Acc	
REQ 195	The Laser System shall be labelled or engraved with nameplates	F			Acc
REQ 196	Name plates and label shall be permanently marked	F			Acc

Reference	Description	Verification method			
		D	A	T	I
REQ 197	All dismountable parts shall be marked	F			Acc
REQ 198	All the cables, connectors and electrical equipments shall be marked	F			Acc
REQ 199	Methods and procedure to design and manufacture the Laser System shall reflect the state of the art in the respective technical fields	P/F	P/F		
REQ 200	Performance prediction using a laser simulation tool and FEM tools		P/F		
REQ 201	Laser simulation tool shall be internationally recognized or validity evidence has to be given		P/F		
REQ 202	FEM tools shall be internationally recognized		P/F		
REQ 203	Structural models used shall be representative		P/F		
REQ 204	Errors due to mesh sampling		P/F		
REQ 205	Boundary conditions		P/F		
REQ 206	Evaluation of the results of the Operational load case and of the OBE load case		P/F		
REQ 207	Evaluation of the results of the Thermal Survival load case and of the MLE load case		P/F		
REQ 208	Earthquake effect investigation		P/F		
REQ 209	Dynamic cross-coupling effect investigation		P/F		
REQ 210	If required, supplementary load cases shall be done		F		
REQ 211	Gravity effect investigation		P/F		
REQ 212	Thermal effect investigation		P/F		
REQ 213	The thermal analysis shall take into account the operational and functional range of temperature		P/F		
REQ 214	Eigen frequency evaluation through a modal analysis		P/F		
REQ 215	Thermal analysis to verify the Laser System performance		P/F		
REQ 216	Conduction, convection and radiation shall be considered		P/F		
REQ 217	The thermal analysis shall take into account operational and functional temperature variations		P/F		
REQ 218	Operational modes to be studied by thermal analysis		P/F		
REQ 219	Thermal analysis outcome: external surface temperature and cooling power required		P/F		
REQ 220	Quality assurance standards	P/F			

Reference	Description	Verification method			
		D	A	T	I
REQ 221	Verification method definition		Acc		
REQ 222	Verification Test Plan	P/F			
REQ 223	The Laser System shall be tested in the operational and functional temperature range	P/F		Acc	
REQ 224	The Laser System shall be tested under operational and functional gravity loads	P/F		Acc	