KAON # 750

Next Generation Adaptive Optics System

Laser Guide Star Facility

Laser Systems Support

Preliminary Design

May 02, 2010

VersionV1.0

Prepared By J. Chin

REVISION HISTORY

Revision	Date	Author (s)	Reason for revision / remarks
1.0	March 10, 2010	Author	Preliminary Design Release

TABLE OF CONTENTS

1 INTRODUCTION

A major component of the Next Generation Adaptive Optics System (NGAO) is the laser system. The laser system will provide the 75W of 589nm light necessary to produce a seven Laser Guide Star (LGS) asterism on the mesosphere. This system was noted as a major risk for the NGAO project during the System Design Phase. During the Preliminary Design (PD) Phase, significant progress has been made to minimize this risk. This document will describe the progress made during the PD phase, the interfaces and infrastructure needed to support the laser system.

2 REFERENCES

2.1 Referenced Documents

Documents referenced are listed in Table 1. Copies of these documents may be obtained from the source listed in the table.

Ref. #	Document #	Revision or Effective Date	Source	Title
1	KAON 510	1.0	WMKO	NGAO Technical Risk Evaluation
2	KAON 511	0.3	WMKO	NGAO System Design Manual
3	KAON 690	2.0	WMKO	NGAO Laser Technical Specifications
4	KAON 749	1.0	WMKO	NGAO Laser Enclosure Preliminary Design
5	KAON 758	1.0	WMKO	NGAO Keck II Laser Removal Plan

Table 1: Reference Document

2.2 Acronyms and Abbreviations

Table 2 defines the acronyms and abbreviations used in this document.

Acronym/Abbreviation	Definition
DDR	Detailed Design Review
ESO	European Southern Observatory
KAON	Keck Adaptive Optics Note
LE	Laser Enclosure
LGS	Laser Guide Star
LGSF	Laser Guide Star Facility
LH	Laser Head
LLHE	Liquid-Liquid Heat Exchanger
LRU	Line Replaceable Units
LU	Laser Unit
NGAO	Next Generation Adaptive Optics System
PD	Preliminary Design
SPL	Seed Pump Laser
SYD	Switchyard
WMKO	W.M.K. Observatory

Table 2: Acronyms and Abbreviations

3 OVERVIEW

The LGSF layout is shown in Figure 1, which was presented during the NGAO System Design Review (KAON 511). This layout assumes the laser system and the Switchyard (SYD) can fit in a single large enclosure as shown in KAON 749. The location of this enclosure was undetermined at the time of the System Design Review. With the completion of the laser manufacturer's PDR, the design has sufficiently progress that the recommendation is to install the lasers and the SYD in the existing Keck II Laser Enclosure on the telescope. The advantage of this design is the lack of a requirement to transport the beam from a Nasmyth platform location onto the elevation portion of the telescope. However, the drawback is the requirement that the lasers must function in a moving gravity environment as it does in the Keck II laser (Figure 2). Since each of the manufacturer's Laser Unit (LU) will generate 25W of sodium light; three LUs will be needed to support the NGAO 75W requirement. Reusing the existing enclosure will result in savings to the project and downtime to support installation of a new enclosure. However, modifications will be necessary to provide the necessary infrastructure for the new LUs.

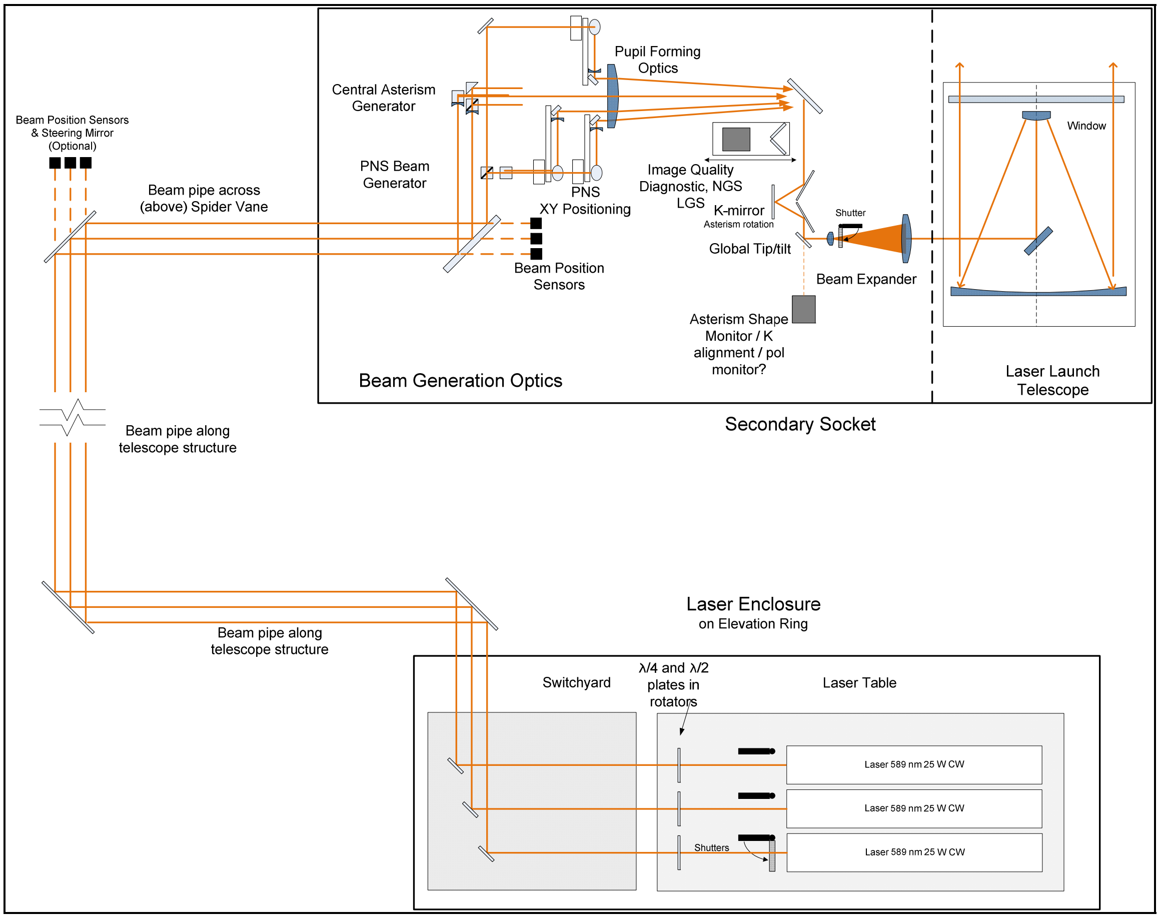

Figure 1: Laser Guide Star Facility

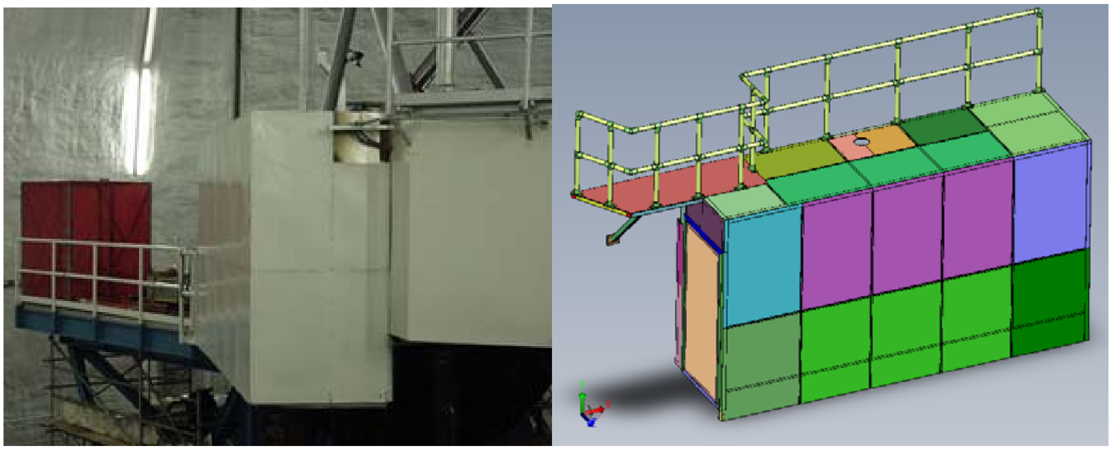

Figure 2: Keck II Laser Enclosure

4 LASER PROGRESS

A consortium of observatory including WMKO, European Southern Observatory (ESO), and the Thirty Meter Telescope was formed to support development of a Laser Unit that all three institutions will benefit from. A year long preliminary design phase led by ESO with two laser vendor finalized with a preliminary design review and a selection of one of the two vendors to continue into the final design phase. The review was held in Dec 2009 and a selection was made in February of 2010. The vendor selected will now move into the next phase which will be the development of a prototype of which the final design will be based on. The data in this document and those supporting the LU are based on information learned during the laser PD phase. During the PD phase, the laser manufacturer completed demonstrations and risk reductions that have met the initial requirements.

5 LASER ARCHITECTURE

The current planned WMKO design of the LU is a combination of the concepts that was developed during the SD Phase. The design takes advantage of one part of the laser residing on the elevation ring to simplify the Beam Transport Optics and a second part residing on the fix Nasmyth Platform to minimize weight and infrastructure requirements on the elevation ring. It does this by splitting the system into two sections: the Seed and Pump Lasers (SPL), and the Laser Head (LH). The SPL is installed in the AO e-vault while the LH is located on the elevation ring (Figure 3). The halves are connected via two umbilical cords, one for electrical/fiber lines and the second for cooling lines. The manufacturer has verified operations using a 37 meter distance between these two locations. A third location to support a heat exchanger near the SPL is also needed near the SPL. The final location will be determined during the AO Enclosure design.

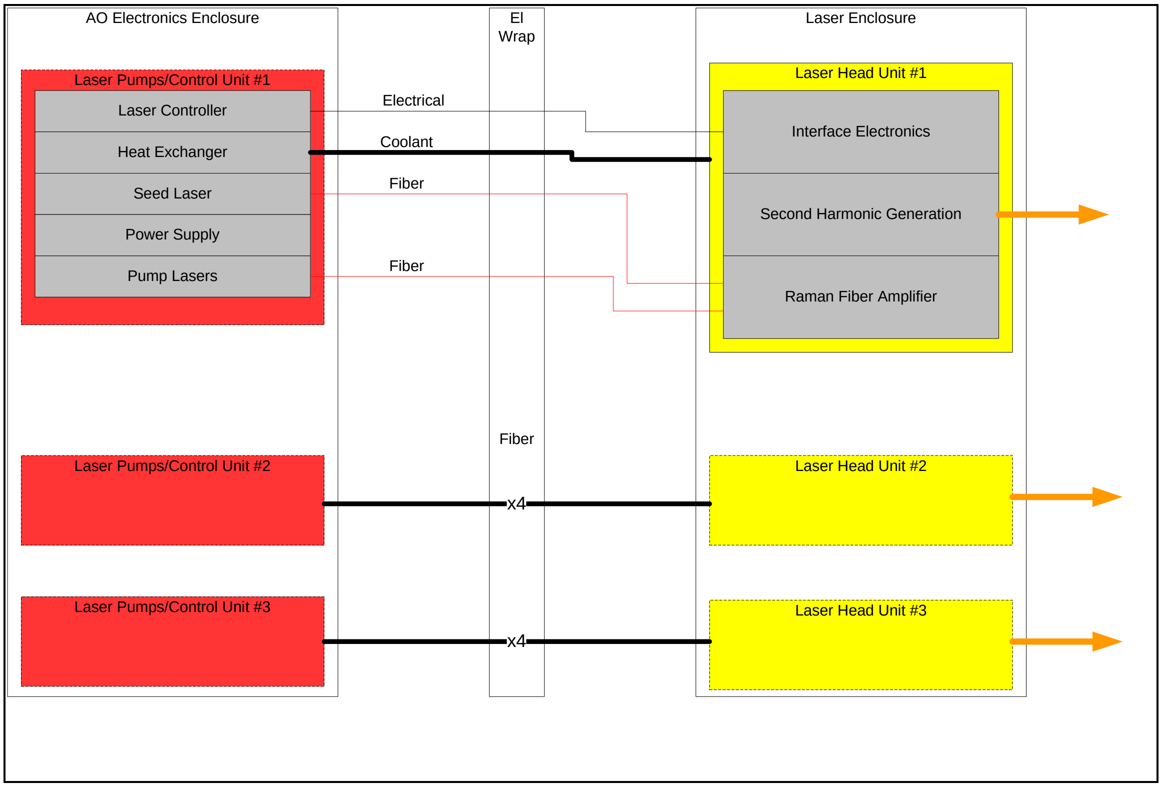

Figure 3: Lasers Layout

6 REQUIREMENTS AND COMPLIANCE

The requirements for the LUs are in KAON 690. Since the laser went through its own PDR with representatives from all three astronomical institutions, compliance is not presented here. There are also non-disclosure agreements between the laser manufacturer and the institutions regarding laser technology and performance.

7 MECHANICAL DESIGN

7.1 Laser Enclosure Layout

KAON 749 provides the justification for the location for installing the LUs in the existing Keck II Laser Enclosure. Figure 4 shows the new layout of three lasers within the existing LE on a mounting frame. The size of the laser heads (yellow) has been chosen based on laser PDR. The optical bench in the middle of the three lasers is the switchyard (SYD_ which formats the three laser beams and sends all three up and out to the Beam Transport Optics on the top of the enclosure, similar to what is currently done on Keck II.

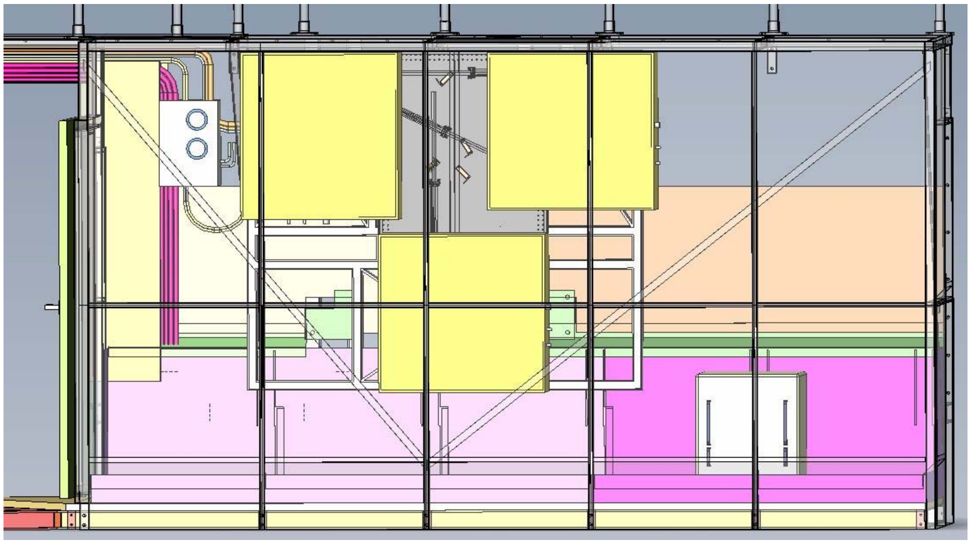

Figure 4: New Laser Enclosure Layout

7.2 Laser Mass and Volume Allocation

To minimize any impact to the telescope, the design of the lasers and the SYD should not exceed the weight of the existing laser table and auxiliary equipment on the elevation ring. A total of 1,700 Kg was removed from the Keck II elevation ring when the Keck II laser system and enclosure was installed. Table 3 shows the estimated mass of the new components. The new system will weigh 775 Kg less than the existing laser table and assembly. This reduction in weight may have a doubling impact on the telescope as an additional 775 Kg may be removed from the back of the elevation ring for telescope balance purposes.

Item	**Keck 2 Laser (Kg)**	**New Laser (x3) (Kg)**
Laser Table	1136	197
Mounting Bracket	75	125
Laser Cabinets	60	60
Dye lines/fittings/Cooling	30	30
Cabling	50	15
Subtotal	**1351**	**427**
Laser Room and Infrastructure	349	349
Total	**1700**	**925**

Table 3: Estimated mass for the new lasers and auxiliary equipments

Table 4 shows the weight added to the AO e-vault which includes the pump lasers, controller, and seed laser. This weight will be countered by the removal of current dye laser electronics in the AO e-vault. The weight of the liquid-liquid heat exchanger is estimated to be 200 Kg.

Item	**Pump Lasers / Controller (Kg)**
Pump Lasers	73.8
Power Supply	35.1
Auxiliary Units	24
Control Unit and Electronics	30
Seed Laser	63

Rack(s)	75
Total	**300.9**

Table 4: Estimated mass for pump lasers and controllers

The volume of the laser heads will be 900W x 850 x 280 D. The laser pump volume will be 600W x 2150mm H x 700mm D fitting into a standard 24" rack. The laser heat exchanger located near the Nasmyth platform will be 770mm W x 1000mm H x 810mm D.

7.3 Glycol Cooling

Due to the technology of the LU, the laser system will require 18°C coolant. This is an issue for the observatory as the nominal instrument glycol and the dome temperatures are closer to 0°C. To provide such this higher temperature coolant, the laser will be cooled by a liquid to liquid heat exchanger (LLHE) located near the SPL in the AO e-vault. Figure 5 shows the current design for such a system.

The commercial LLHE will be controlled by a Programmable Logic Controller (PLC); which will be in communication with the laser controller. The PLC will monitor sensors and shut down the LLHE if necessary. The PLC will also have a network interface for any system to query its status and temperature settings. The LLHE will be sized to be able to support all three lasers with redundancy. The expected heat load of the LLHE will be 4.75kW which includes the power consumption of the LLHE.

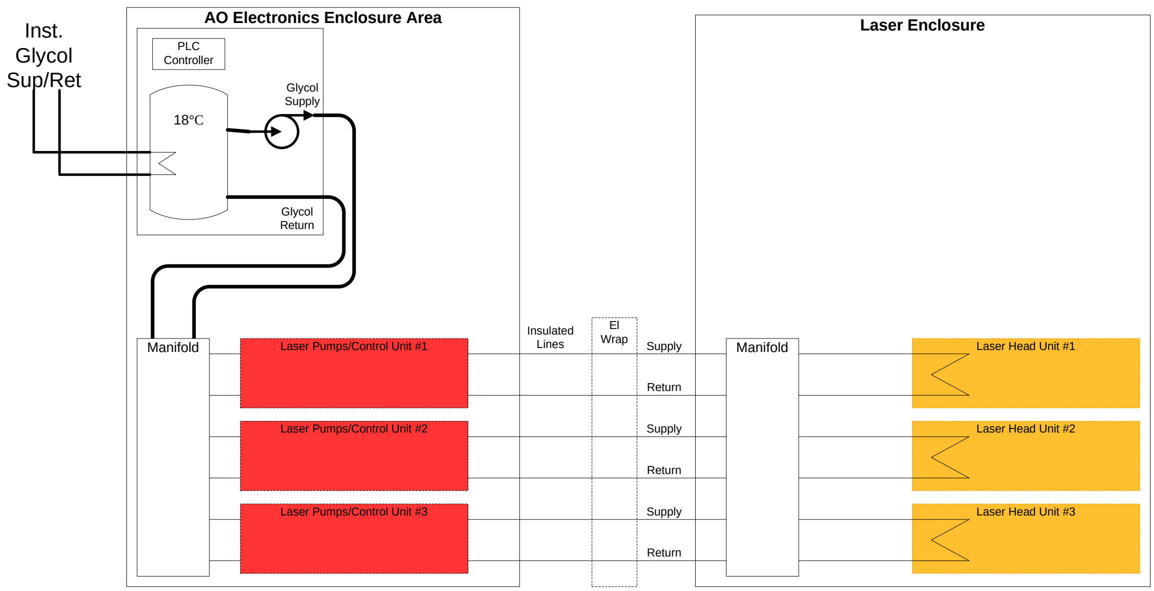

Figure 5: Laser Unit Heat Exchanger

Due to the 18°C operating temperature, the glycol lines must be insulated to minimize radiation into the dome. The observatory is current moving away from the standard Goodyear gorilla hoses to a new Goodyear hose called the viper for instrument glycol. This is not an insulated line and must be insulated accordingly. Estimates from the laser manufacturer require insulation that will increase the diameter to 2".

The location of the LLHE is recommended to be near the AO e-vault where the SPL is located. Pumps within the LLHE may also be a source of vibration. The laser manufacture is working with the pump manufacturer to minimize any vibration. In addition, it is recommended the LLHE is installed in such a way to minimize vibration. Vibration isolation mounting techniques such as suspending the unit should be employed during the design phase. If the unit is mounted below the AO enclosure, installation of the unit should also be considered as there is not a way to lift the unit in place using overhead cranes. Scissor lift type jacks may not be sufficient high enough to reach these locations.

Since the LH will be located 37 meters away from the SPL, the six cooling lines must also be insulated to prevent radiation into the dome. The thickness of such insulation must be considered for the wraps as well as its routing to the Laser Enclosure along the elevation ring. Existing mechanical struts to secure cables were provided for the Keck II laser and will need to be upgraded for the new glycol lines.

7.4 Laser Installation and Servicing

A laser installation plan shall be generated as part of the laser detailed design. The design of the laser mounting will be similar to how the Keck II laser was installed. Subsequent to Keck II Laser Removal (KAON 758), the laser will be mounted together with the SYD using a mounting frame as described in 9.1.1. The entire system will be lifted as a single unit (Figure 6) once the LE shell is removed.

For future laser mounting or removal, the top panel/structure of the LE will be modified to be removable for a crane to lift the unit in/out of the LE. This modification is part of the LE design. A manual lifting mechanism may be provided by the laser manufacturer or design within the NGAO project. This structure will be used to balance and position the laser in the tight space within the LE.

Figure 6: Laser Mounting onto Elevation Ring

8 LASER SAFETY

The LU is a Class IV laser and is certified by the Center for Devices for Radiation Health (CDRH). By doing so, all safety features and interlocks will be verified to CDRH standards. In the current methodology for laser servicing, the laser controller shall perform health checks and inform the user of required maintenance. In some instances, the system will modify internal parameters to meet system performance. The user will only replace Line Replaceable Units (LRU) as necessary. Unlike previous laser systems, the simplicity of this laser will minimize the activities requiring opening the laser itself.

A hardware interface between the laser system and the safety system will maintain laser safety and will shut the laser down if necessary. The hardware interface is located in the AO e-vault where both systems will reside. The details of this interface are provided in the next section.

9 INTERFACES

The effort to provide for these interfaces are assumed to be part of the laser design and integration process unless where specified otherwise.

9.1 Mechanical

9.1.1 Mechanical Interface to the Laser/SYD mounting frame

The frame to support the three LHs and the SYD will be similar to the existing frame that supports the existing laser table. The frame will be stiffened appropriately at the mating points to the LHs and SYD and its six attachment points to the elevation ring. The attachment points are shown in green in Figure 6 (Additional bracing will be added over the pads for mounting). The existing laser table will be removed off of these points as a single unit and the new laser assembly will be attached as a single unit. Once installed, the laser unit and the SYD can be removed individually for maintenance and servicing as needed. Additional hardware mechanisms will be required to insure alignment repeatability. Any misalignment can be removed by the tip-tilt stages within the SYD. The final design will be finalized by DDR after further development of the LH design. The design of the mount will be part of the LE design, the installation of the mount will be part of the laser integration effort.

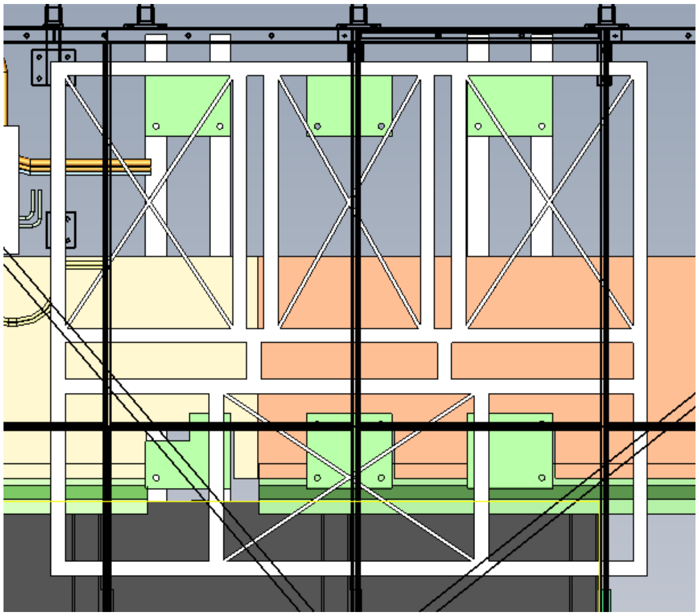

Figure 7: Lasers and SYD Support Frame

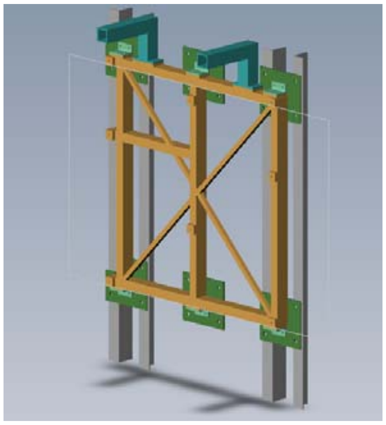

Figure 8: Current Keck 2 mounting support structure

9.1.2 Glycol lines in the telescope

Six insulated lines will be run from the AO e-vault to the LE. The lines will be ½" each without insulation running a total of 7.5 LPM of 18°C glycol. The length is approximately 37 meters. Special considerations will have to be made to ensure heat does not dissipate into the dome. The design of the heat exchanger installation will be part of the AO enclosure design effort. Installation and integration will be part of the laser effort.

9.1.3 Mechanical Interface to the AO Electronics Vault

The three SPL will have a mechanical interface to the AO e-vault. All LU units will be able to be rack mounted with a maximum 700mm D x 700mm W. The height shall be 1.2 mm. During the detailed design phase, an examination will be done to determine if the units can be combined into a single tall rack. The mass of the three units will be 300 kg combined.

9.1.4 Cooling interface to the AO Electronics Vault and LE

As shown in Figure 5, two manifolds will be needed, one for the SPLs and one for the LHs. The manifold will include will support quick disconnect lines to minimize fluid lost during LRU maintenance. The connector types will be determined by DDR. The design effort for the manifolds will be part of the AO e-vault design.

9.2 Optical Interfaces

Each LU will have an optical interface to the SYD. Both the LU and SYD will reside on a mounting frame as shown in Figure 4 and Figure 7. Each LU shall deliver a collimated beam, with an output beam waist diameter @ $1/e^2$ equal to 3.0 mm ± 0.1 mm. The effort for this integration will be addressed by the SYD design.

In addition to the SYD interface, the fibers between the SPL and the LH will require special tooling. Unlike connectorized communications fibers used at the observatory, these fibers will require to be spliced and fused when the LRU needs to be replaced. Splice boxes will reside at each end of the fibers.

9.3 Electrical or Electronic Interfaces

9.3.1 Electronics Interface to the Observatory Network

The LU will have a hardware network interface conforming to TIA/EIA standard TIA/EIA-568-B. The CAT5 connection will go between the laser controller and the network switch within the AO E-vault.

9.3.2 Electronics Interface to the Safety System

The LU will have a hardware interface to the Safety System. Both subsystems are located within the AO e-vault; therefore the cabling will be minimal. The connector for the LU is still TBD from the manufacturer; but will be an MS Mil-Circular type with a minimum of 15 pairs. The signals will be EIA485 compatible difference signals for safety. These are shown in Table 5:

#	Signal	Input from/Output to	Description
1	Emission ON	Output	1 if the Laser Unit is generating laser light
2	Safety Status	Output	0 if an internal safety fault is present
3	Emergency Shutdown	Input	0 to stop any light generation
4	Emergency Power Shutdown	Input	0 to shutoff power to the entire system
5	Output shutter closed	Output	1 if the output shutter is closed

6	Output shutter fault	Output	0 if there is a fault in the output shutter
7	Output shutter permissive	Input	1 to allow the output shutter to open
8	Exposed Hazardous Radiation	Output	0 if there is exposed hazardous radiation; may be represented by the "Safety Status"
9	Laser System Fault	Output	0 to denote there is an internal fault
10	Laser Interface Fault	Output	0 to denote the interface is not operating correctly such as differential signal representing two "1"s or two "0"s.

Table 5: Laser Interface Signals to SS

9.3.3 Electrical Power

The LU power requirement has not been finalized yet, the baseline will be standard 3 phase 208VAC to the LUs. The connectors for the power are currently TBD. Since the majority of the power is located in the AO e-vault, the effort for supporting laser power will be part of the AO e-vault activities. The required power for the three lasers and the LLHE combined is 5kW of UPS power.

10 OPERATIONS

10.1 Laser Servicing Models

The laser manufacturer has documented a list of failure modes and remedies. The vendor has also provided three separate models for servicing the LU. The first is the standard replacement of the entire LRU with a spare unit on site. This is unlikely as there are cost constraints of having a full spare system. A second model is to have WMKO personnel service the LUs, this will require training as well as the necessary facilities, clean rooms and test stations. Failed unit may still need to be sent back to the manufacturer for repair. The manufacturer will keep a set of common spares for all users of the LU. This may result in the less down time; but may require initial investment for the project for spares and training.

The final model is to send the failed unit back for repair. The manufacturer will immediately send a spare out to the observatory once the problem is isolated. This model will require the least amount of initial investment and a reasonable down time. WMKO will be working with the manufacturer and ESO to determine the best model for laser servicing. More data shall be provided during DDR at the end of the laser final design phase.

10.2 Laser Tooling

In order for any of these models to function, WMKO will require some investment in fiber tooling. These may include a fiber microscope and/or a commercial fusion fiber splicer used in the telecom industry. The cost of this tooling is in $34K.

10.3 Laser Maintenance

The laser itself will perform internal self-checks to determine if there are problems during startup and normal operations. Some problems will be remedied by the laser itself such as alignments. However, if a problem cannot be "self healing", the system will issue warning and or faults via its software interface. Warnings inform the operator of impending faults that should be address soon prior. Performance is maintained during warnings.

Aside from self checks, the laser manufacturer is recommending an annual inspection either by WMKO or a technician from the laser manufacturer. The following checks are recommended to be completed for regular maintenance:

- Inspection of the cooling system
- Inspection and test of all safety installations

- Inspection of cabling
- Inspection on system degradation and preventive exchange of critical components or components close to their end of life
- Verification of the performance status of the on-site spares if any
- Refresher training of staff by the manufacturer

11 DELIVERABLES

Figure 9 shows the deliverables for the LE.

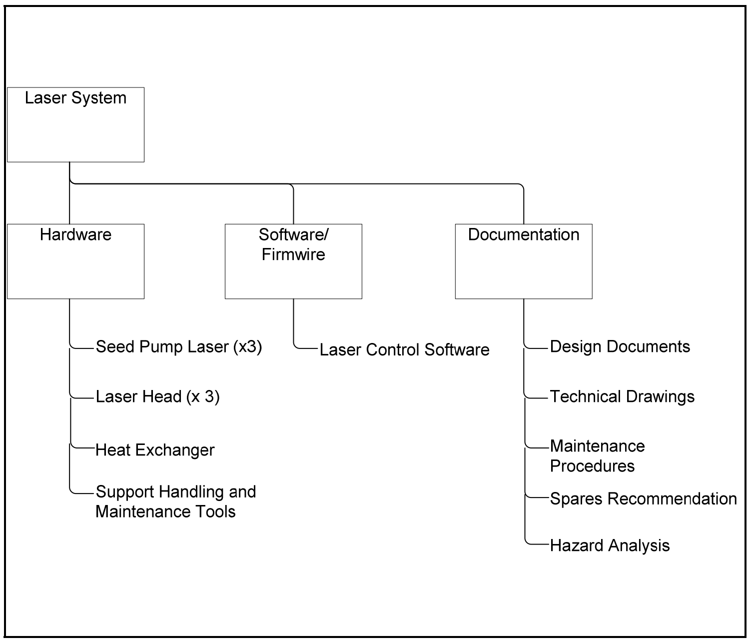

Figure 9: Laser Deliverables

12 MANAGEMENT

12.1 Risk and Risk Reduction Plan

A major risk that was brought up during the mini-review regarding the size of the laser systems has been put to rest. The current NGAO laser system is sufficiently small that all three lasers will fit in the existing LE. One new risk arose based on the requirements from the laser manufacturer.

Table 6 shows individual risks within LE in accordance with KAON 510.

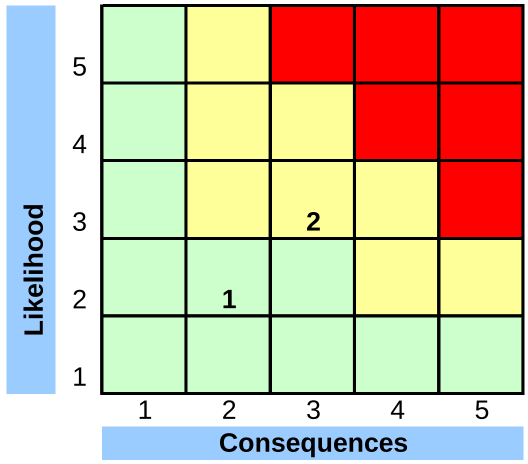

Table 6: Risk Matrix

#	Consequence	Likelyhood	Description	Status	Mitigation
1	2	2	Laser system cooling	A design is in place to support this requirement; however, more study is needed to ensure there is no major impact to the telescope.	During DDR, the current design will be vetted to ensure it will not be detrimental to the telescope or observing.
2	3	3	Laser system requirements and associated cost	Discussions are still being held with the laser manufacturer to define the requirements and interfaces related to WMKO.	By DDR, these requirements / interfaces and their cost implications should be known.

Table 7: Risk Analysis

12.1.1 Laser System Cooling

The current lasers require 18°C at the laser heads in order for it to operate. Within the laser head, sufficient insulation is provided to ensure this heat is not an impact for the environment. However, 18°C glycol lines can be a problem and if not insulated properly emit heat into the dome. The current design of such a system is in the laser design document. During DDR, a more thorough investigation shall be made to ensure the system will be sufficiently insulated to not radiate heat into the dome. Testing with hoses and insulation will reduce this risk during the DD phase.

12.1.2 Laser System Interfaces

Although significant progress has been made by the laser manufacturer, there are still interfaces that must be defined as well as delta requirements that are not part of the consortium design. These changes will impact the cost of the laser system somewhat. A final design review will be held in mid 2011 for the laser system and the final design will be updated for the NGAO detailed design.

12.2 Budget

This section will be presented separately at the PDR.

12.3 Schedule

The delivery of the three LUs will be phase to support MRI Next Generation Laser Proposal and NGAO. The initial laser will be delivered and will undergo extensive laser interface testing with a laser controller and the beam transport system. Expedient delivery to the summit is critical to support the MRI proposal. With the experience gained from LU #1, LU #2 will go through extensive testing with the NGAO Laser Launch Facility components such as the SYD, BTO, and BGS. All asterism generation can be tested with a single laser by folding the beam into its needed configurations. LU #3 will go through minimum testing to assure its performance are met as LU#1 and LU#2 should have provided the system level testing. Final end to end testing with all three lasers will be completed at the summit. The schedule for the delivery and acceptance is shown in

WBS	Task Name	Start	Finish	Work
1	**⊟ NGAO Lasers 5.2**	**Fri 10/1/10**	**Fri 5/8/15**	**4,240.43 hrs**
1.1	**⊟ Project Management & Reviews**	**Fri 10/1/10**	**Thu 2/13/14**	**0 hrs**
1.1.1	**⊟ Reviews & Milestones**	**Fri 10/1/10**	**Thu 2/13/14**	**0 hrs**
1.1.1.1	Project Start Date	Fri 10/1/10	Fri 10/1/10	0 hrs
1.1.1.2	Laser 2 Removal Decision	Fri 2/1/13	Fri 2/1/13	0 hrs
1.1.1.3	Laser #1 Arrival	Fri 4/26/13	Fri 4/26/13	0 hrs
1.1.1.4	Laser #1 Pre Telescope Review	Thu 6/27/13	Thu 6/27/13	0 hrs
2.0.20	K2 Laser goes Offline	Thu 8/1/13	Thu 8/1/13	0 hrs
1.1.1.6	Laser #2&3 Arrival	Mon 12/30/13	Mon 12/30/13	0 hrs
1.1.1.7	Laser #2&3 Readiness at HQ	Thu 2/13/14	Thu 2/13/14	0 hrs
1.2	**⊟ Detailed Design Phase 5.2**	**Fri 10/1/10**	**Tue 4/3/12**	**1,412.97 hrs**
1.2.1	DD Phase Reporting and Planning	Fri 10/1/10	Sat 3/24/12	157.23 hrs
1.2.2	**⊞ Laser Procurement**	**Fri 10/1/10**	**Tue 4/3/12**	**691.72 hrs**
1.2.3	**⊟ Engineering Tasks**	**Mon 4/4/11**	**Fri 10/7/11**	**508 hrs**
1.2.3.1	**⊞ Laser Control Software Design**	**Tue 4/5/11**	**Wed 5/18/11**	**312 hrs**
1.2.3.2	**⊞ Laser Controller H/W Design**	**Mon 4/4/11**	**Thu 4/28/11**	**76 hrs**
1.2.3.3	Laser I&T Test Plans	Fri 9/30/11	Fri 10/7/11	120 hrs
1.2.4	Design Review and Documents	Fri 10/7/11	Fri 10/14/11	56 hrs
1.3	**⊟ Full Scale Implementation Phase 5.2**	**Sat 3/24/12**	**Mon 12/30/13**	**1,246.03 hrs**
1.3.1	FSD Phase Planning and Reporting	Sat 3/24/12	Thu 11/14/13	144.6 hrs
1.3.2	**⊟ Engineering Tasks**	**Tue 4/3/12**	**Mon 12/30/13**	**1,045.43 hrs**
1.3.2.1	**⊟ Laser Procurement**	**Tue 4/3/12**	**Mon 12/30/13**	**685.43 hrs**
1.3.2.1.1	**⊞ Laser Phase 3 Unit #1 Delivery**	**Tue 4/3/12**	**Fri 4/26/13**	**382.72 hrs**
1.3.2.1.2	**⊞ Laser Phase 3 Unit #2&3 Delivery**	**Tue 4/3/12**	**Mon 12/30/13**	**302.72 hrs**
1.3.2.2	**⊞ Laser Tooling**	**Tue 4/3/12**	**Mon 8/20/12**	**32 hrs**
1.3.2.3	**⊟ Laser Control Software Development**	**Tue 9/25/12**	**Mon 10/29/12**	**240 hrs**
1.3.2.3.1	**⊞ Laser Interface Software**	**Tue 9/25/12**	**Mon 10/15/12**	**152 hrs**
1.3.2.3.2	**⊞ Laser Operational Software**	**Mon 10/15/12**	**Mon 10/29/12**	**88 hrs**
1.3.2.4	**⊟ Laser Controller H/W Development**	**Tue 10/30/12**	**Wed 10/31/12**	**28 hrs**
1.3.2.4.1	**⊞ Laser Interface Controller**	**Tue 10/30/12**	**Wed 10/31/12**	**28 hrs**
1.3.2.5	Laser I&T Test Plans	Thu 11/1/12	Mon 11/5/12	60 hrs
1.3.3	Review and Documents	Mon 11/5/12	Mon 11/12/12	56 hrs
2.8	**⊟ Delivery and Commissioning 5.2**	**Thu 4/18/13**	**Fri 5/8/15**	**1,581.43 hrs**
1.4.1	DC Phase Planning and Reporting	Thu 4/18/13	Fri 5/8/15	183.43 hrs
1.4.2	**⊞ Laboratory Integration & Test**	**Fri 4/26/13**	**Tue 2/18/14**	**992 hrs**
1.4.3	**⊞ Post Installation**	**Mon 2/3/14**	**Wed 5/6/15**	**406 hrs**

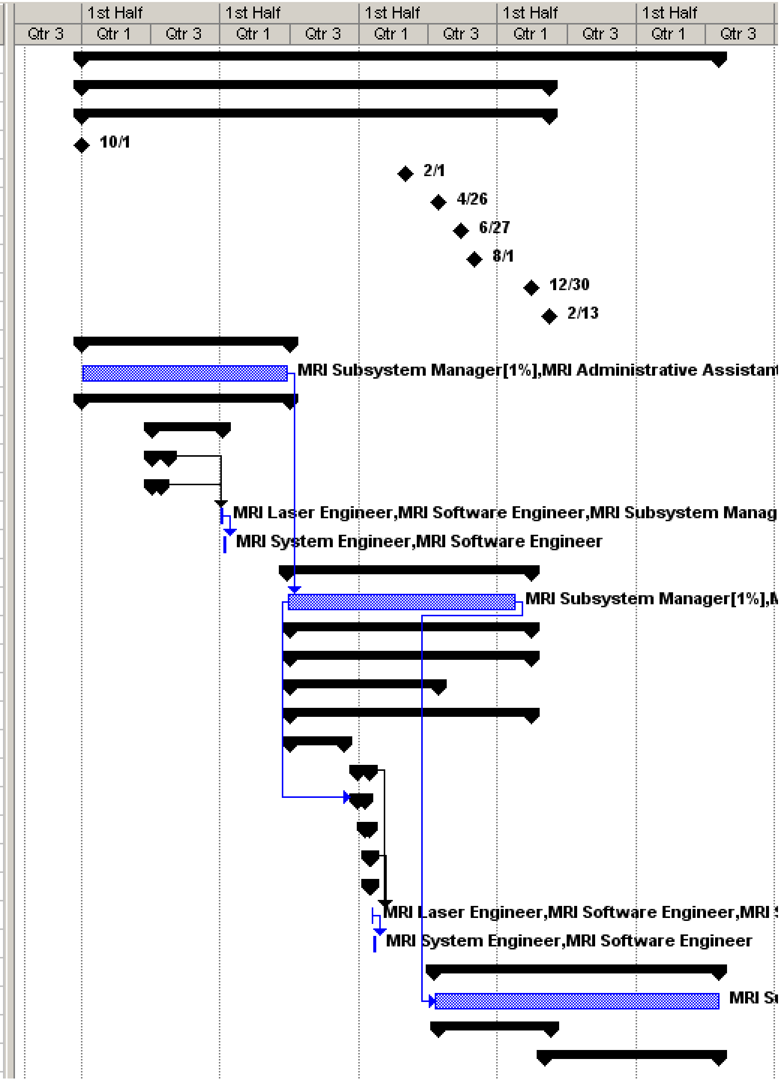

Figure 10: Laser Acquisition and Acceptance Schedule

13 PLANS FOR THE NEXT PHASE

In the DDR phase, the following designs will be completed in preparation for the Full Scale Implementation phase.

13.1 Laser Progress Monitoring

The laser manufacturer will be completing the detailed design of the laser. WMKO will continue to support the consortium as possible to ensure the laser can be operated at Mauna Kea.

13.2 Laser Infrastructure Design

The designs shall be completed to ensure support of the three lasers and the heat exchanger. The design shall be finalized as to the location of the heat exchanger and analysis shall be completed to ensure the radiated heat into the dome is not an issue. Procurement quotes shall be provided.

13.3 Laser Installation Plan

An installation plan shall be provided to support the laser after its detailed design phase.

13.4 Laser Proposal

WMKO will continue to seek proposal opportunities to implement one laser at the observatory in support of NGAO. The jump-start program will greatly reduce the risk associated with the installation of three lasers.

13.5 Updated documentation

All documentation shall be updated for risk, budget, and schedule for the Detailed Design phase.