KAON # 752

Next Generation Adaptive Optics System

Laser Guide Star Facility

Safety System Controller Assembly

Preliminary Design

May 10, 2010

VersionV1.0

Prepared By Jason Chin

REVISION HISTORY

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

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1 INTRODUCTION

As part of the Next Generation Adaptive Optics System (NGAO), a Safety System Controller (SSC) is needed to ensure the laser facility operates safety and in accordance with regulatory standards for operating a laser. These standards include the American National Standards Institute (ANSI) Z136.1 Safe Use of Lasers and Z136.6 Safe Use of Lasers Outdoors. The standards are to ensure safety for internal personnel and equipment, as well as external assets such as aircrafts and space vehicles.

Similar systems were developed for the Keck I and Keck II laser systems. The NGAO design will leverage the technology and knowledge gain from these two systems. This document provides the preliminary design for the NGAO Safety System Controller.

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 753	1.0	WMKO	Safety System Interface Control Spreadsheet
2	KAON 510	1.0	WMKO	NGAO Preliminary Technical Risk Evaluation
3	ANSI Z136.1		ANSI	Safe Use of Lasers
4	ANSI Z136.6		ANSI	Safe Use of Lasers Outdoors

Table 1: Reference Document

2.2 Acronyms and Abbreviations

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

Acronym/Abbreviation	Definition
AB	Allen Bradley
DD	Detailed Design
FAA	Federal Aviation Adminstration
FSD	Full Scale Develoment
ICD	Interface Control Document
KAON	Keck Adaptive Optics Note
LE	Laser Enclosure
LGS	Laser Guide Star
LGSF	Laser Guide Star Facility
LTCS	Laser Traffic Control System
NGAO	Next Generation Adaptive Optics System
PLC	Programmable Logic Controller
SSC	Safety System Controller
WMKO	W.M.K. Observatory

Table 2: Acronyms and Abbreviations

3 REQUIREMENTS

The functional requirements for the SSC are generated to support practices outlined in the American National Standards Institute's Z136.1 Safe User of Lasers and Z136.6 Safe Use of Laser Outdoors standards for laser operations. These documents provide the guidance for the flow down from which the system is designed.

4 DESIGN SELECTION METHODOLOGY

The design of the NGAO SSC is based on existing designs for the Keck II and Keck I laser systems. In Keck II, a Modicon Programmable Logic Controller (PLC) System is used for laser control and laser safety. PLCs are used for their reliability as well as ease of programming. The Keck II system is comprised of two PLCs with one acting as a master and the other working as a slave. The master resides in the laser room on the dome floor and the slave resides in the AO electronics vault. The split system was to provide input/outputs near signal origination. The master unit supported the laser room and the slave unit supported the laser table on the elevation ring.

Unlike the Keck II laser design, the Keck I laser is situated on the Right Nasmyth Platform next to the laser system. Keck I also used a PLC design for its safety system; but from a different manufacturer. Keck I chose the Allen Bradley SLC500 since it was an established unit at the observatory used for the Interferometer AutoFill System. Since the laser and the Laser Enclosure (LE) are on the Right Nasmyth Platform, the PLC also resides in the LE and has been operating without problems. The Keck I design is shown in Figure 1. The design can be found in the K1 LGS AO Safety System Design Report V1_0.doc.

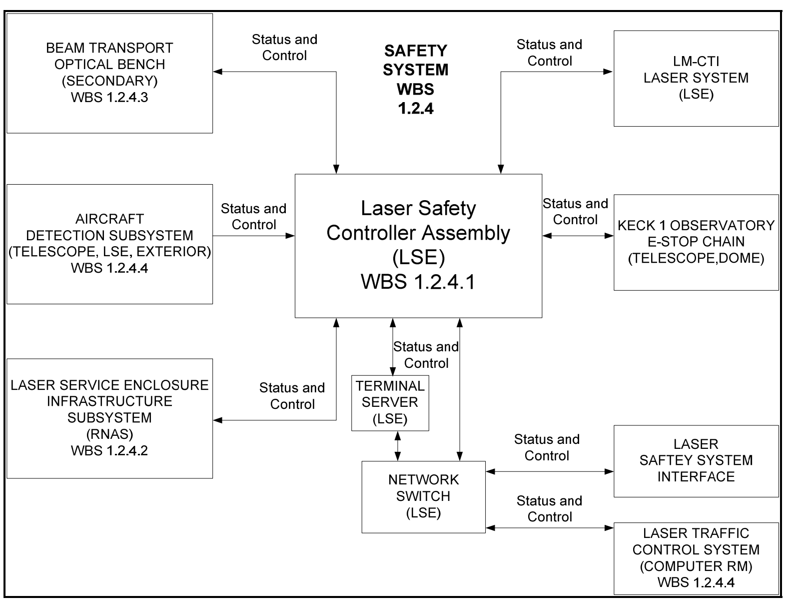

Figure 1: System Design.

For the NGAO design, the major factor for the design was a system that can support multiple laser and beam subsystems at multiple locations. Cost is also a major consideration. To reduce cost, the NGAO will leverage off Keck I's design. A single PLC will be located in the AO e-vault next to the three laser controllers. The advantage of the vault is that it will be temperature controlled and co-located with the three laser controllers. The major disadvantage is that the unit will be further away from the LE and the secondary location from which devices must be integrated with the PLC.

Depending on the final configuration of the AO Enclosure, it is possible there will not be sufficient space to support the full size of the PLC assembly. If this becomes true, the design can be split into two or more subsystems using Allen Bradley's remote I/O link. This link is capable of distance up to 10,000 ft. The design choices will be to locate a station in the Laser Enclosure, AO Enclosure, and possibly off the telescope. The cost of the additional sub-units may be offset by the cost reduction in cabling and the labor for running cables through the telescope. For simplicity, the baseline design will be a single PLC assembly in the AO Enclosure.

5 DESIGN

5.1 Design Functions

The SSC design can be primary flowed down from the requirements to set of interfaces to determine laser propagation in support of ANSI standards. Figure 2 shows the subsystems the SSC will interface with to provide safe operations. The SSC:

- Receives shutter permissive from the Laser Traffic Control System
- Receives shutter permissive from the Aircraft Detection System
- Receives shutter permissive from the Laser Clearinghouse System
- Receives shutter permissive from the Telescope/Dome Drive and Control System
- Receives and provide status to the Facility Infrastructure
- Communicates with the Laser Control and Sequencer
- Communicates with the three lasers for status and control
- Receives status and provide control for personnel operating in the Laser Enclosure and Secondary Module.

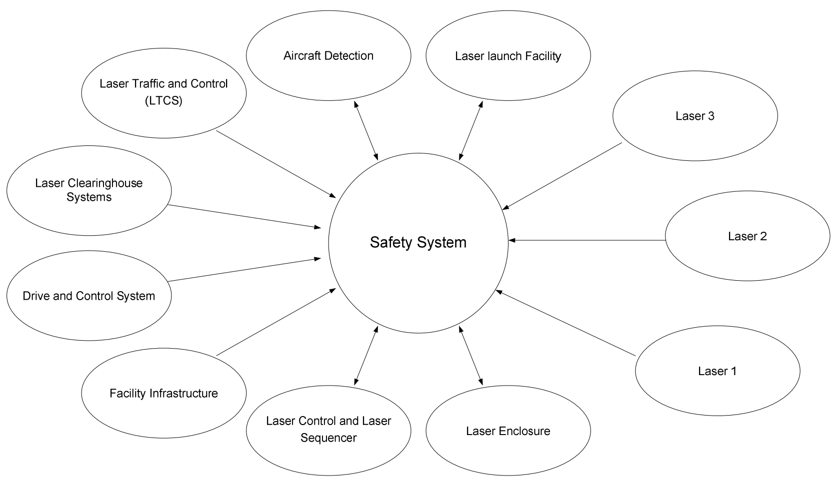

Figure 2: Safety System Interfaces

5.2 System Physical Layout

Figure 3 shows the layout of the SSC and the subsystems it communicates with and their locations. The SSC will be located in the Keck II AO e-vault as the baseline design. In the computer room, computer systems will provide information to the SSC for permissive to propagate the laser on-sky. These include the Laser Clearing House, Laser Traffic Control System, Drive and Control System, and possibly the AO System, the interface to these are purely network and will not require additional interfaces other than a single CAT5 cable. In addition to the network interface, hardware will be needed to provide auxiliary status such as E-Stops and spotters equipment if necessary.

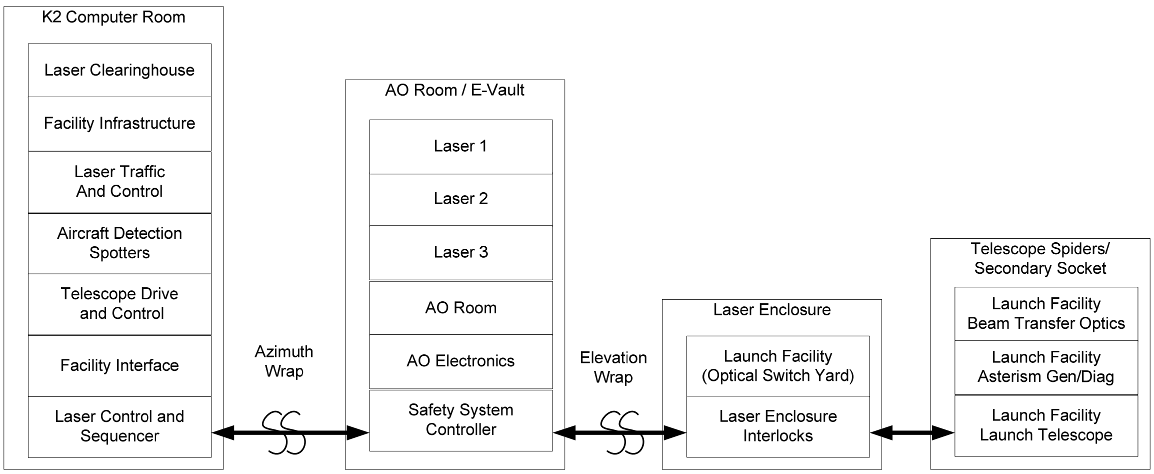

Figure 3: Safety System Layout

The AO e-vault location will provide direct support for the lasers. Each laser interface will provide status and control for its shutter and controls for shutdown of the laser. Part of the laser will be located in the laser enclosure on the telescope elevation ring. The laser enclosure will provide status on environmental data such as door and safety cover status to ensure hazardous radiation is contained. In return, the SSC will provide status for personnel prior to entry into the enclosures. Emergency stops will be located at the enclosures and the secondary location. At the secondary location, the SSC will provide similar features as the LE and controls the fast and final shutter.

5.3 Mechanical

5.3.1 Layout

The layout of the SSC is shown in Figure 4. The physical layout is for the unit to be mounted into a 19" Electronics Rack in the AO e-vault. Because of its location in AO e-vault, the mass, power and heat dissipation is not as crucial as it would be on the telescope elevation ring. However, keeping it small in volume would be advantageous considering all the equipment that will have to be in the AO e-vault.

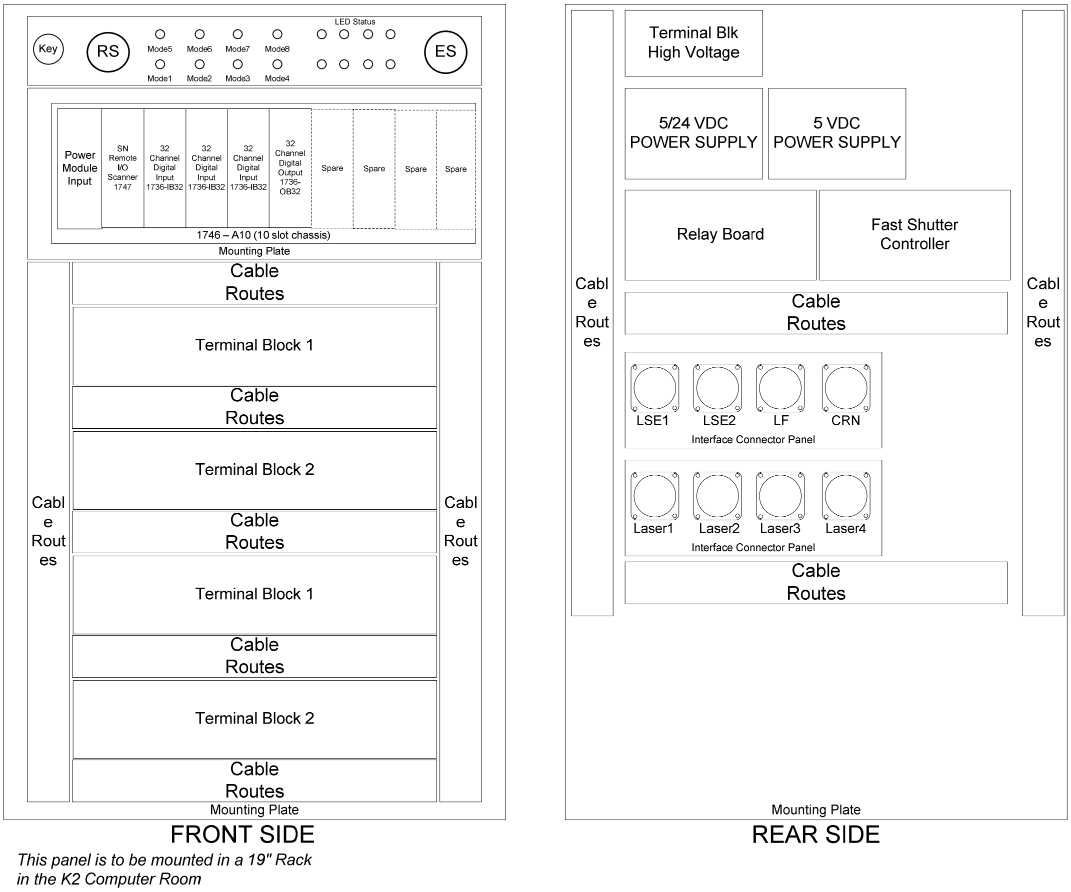

Figure 4: AO Electronics Vault Node Layout

5.3.2 Volume

The volume of the computer room node is estimated to be 19"W x 24"H x 12"D, based on the Keck I SSC design. The AO e-vault volume is estimated to be 19"W x 36"H x 12"D. The sizing of this unit allows it to fit within a standard 19" electronics rack.

5.3.3 Mass

The AO e-vault assembly is estimated to be 25 Kg based on the unit delivered for Keck I.

5.4 Electrical

5.4.1 Electrical Power

The power required is estimated to take 500W maximum. This is based on the design of the Keck I SSC.

5.4.2 Heat Dissipation

The 500W heat generated by the system will need to be removed from the e-vault as part of its convective cooling. No liquid to liquid heat exchanger is planned for the safety system.

5.4.3 Programmable Logic Controller

The AB SLC500 is an established PLC controller in industries and has been used at Keck for two other systems. The life expectancy for the SLC500 is at least another decade according to AB website. At least 4 personnel at Keck have experience with programming and troubleshooting of the SLC500 system. Keck has a software development environment as well as an operational platform for maintenance and troubleshooting of the SLC500.

5.5 Software / Firmwire

There are two aspects to the software. The first is the ladder logic code that operates on the PLC providing controls of the safety system. This code controls the interlock and permissive of devices based on sensor inputs. The code will be similar to the existing Keck I PLC code. Some changes are expected based on the new laser interface and an additional LE; but the fundamental interlocks sequences should be similar.

The second part of software is the interface drivers between the PLC with the Laser Interface System (LIS). In Keck I, the interface goes through the Ethernet network. This network has some disadvantages as it goes through the network switches and terminal servers causing some uncertainty in the timing. The multiple layers of software drivers created some minor problems in Keck I. For NGAO, the layers of software drivers may be eliminated with a direct CAT5 connection. This simplifies the design and removes an additional serial communications layer; the Keck I strategy will be the fall back position. The software that runs with this interface such as alarm handlers and sequencers are not part of the SSC.

5.6 Operational Modes

To assist in the operation of the system, interlocks may be required to be bypassed for alignment purposes. An example for this is the bypass of interlocks allowing propagation of the beam on the dome wall or bypassing of power verification during alignments. Additional operations modes may include the prevention of light out of certain part of the subsystem. An example of this is the forcing shutters to be closed because the f/15 module that receives the laser beam is out of the telescope. These modes must be accounted for normal operations. To assist with these requests, a set of switches in the Keck II computer room will be available for the users. The switches are defined below:

1	In dome operations	Allows opening of the fast shutter for alignment purposes in the dome.
2	Alignment bypass	Bypasses power interlocks during alignment of the laser and BTO
3	Beam Transfer Beam Tag Out	Forces the laser shutter to be closed due to missing components down the BTO beam train
4	Low Power Mode	Allows the bypass of interlocks during low power operations

Table 3: Operational Modes

5.7 Safety Controls

5.7.1 Engineering Controls

5.7.1.1 Safety Shutters

Unlike previous laser systems, the NGAO system will have a combination of 7 laser beams. To support diagnostics at the f/15 location, the final shutter is located just prior to the launch telescope. This location provides a challenge as the shutter has to cover a large area to shutter 7 laser beams (28mm) and yet fit into a compact size of the BGS. To provide a fast reaction time for the shutter, the area covered by the shutter is kept to a minimum, usually 15mm or less. To support this, the system has device a two shutter approach. A final “slower” shutter is located just prior to the launch telescope. A fast shutter will be located in the switchyard area in the laser enclosure. The fast shutter will be used to terminate beam propagation on sky in an emergency. Under normal conditions, the final shutter will be used for on-sky propagation.

It is also important to provide shutter redundancy in the system if one shutter fails. In the current design (Figure 5), there will be four beam blocks in the beam paths, the laser output shutter, the fast shutter, a beam dump for measuring power at the switchyard, and the final shutter.

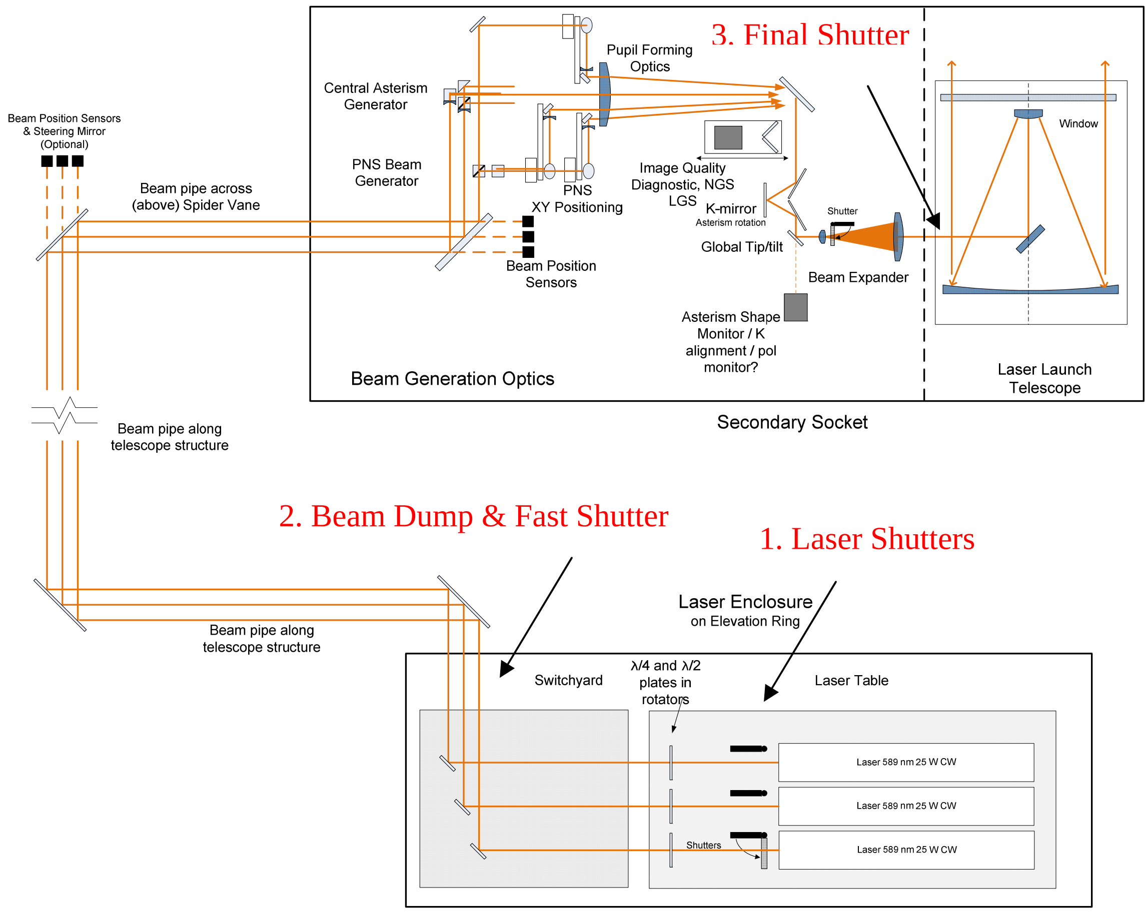

Figure 5: Laser Facility and Shutters

Location 1 shows the laser shutters provided by the laser vendor. Each laser will be provided an output shutter as a requirement of the laser system. There may be additional shutters within the lasers themselves; but they will not be considered in the redundancy discussion. This shutter is closed during reconfiguration of the switch yard. Location 2 is subsequent to the switch yard. Shutter(s) will be provided to enable or disable the beams going to the Beam Transfer Optics. A beam dump is also provided to measure laser power at this location and serves as a beam block. Location 3 is subsequent of the asterism generator and diagnostics. The shutter is placed here to allow the diagnostics to operate with this shutter closed. This shutter will be a larger shutter; therefore is not used as the safety or fast shutter. Shutters located in these locations or a combination of these locations will provide the redundancy necessary for the laser shutter. The number of shutters may be reduced once the beam sizes and space allocation is finalize during the Detailed Design Phase.

The shutters used for the termination the beam should have the following characteristics in order to meet the safety system requirements. The shutter shall operate in a failed safe mode. The shutter shall terminate the laser beam if the shutter is not energized. The shutter should not rely on gravity for operations. The shutter shall have devices to determine its position. The devices will be sensed by the safety system to ensure proper location. The devices themselves shall also be failed safe. Disconnection of the devices will result in an faulted position. The fast shutter shall terminate the beam in a time that is acceptable to meet the safety requirement. The shutter shall close within 1 sec after initiation of closure. The shutter can be combined with a beam dump and measurement device (power) to minimize components. If the shutter is used as a beam dump, proper liquid cooling must be used for heat removal.

5.7.1.2 Sensor Interlocks

The safety system protects personnel and equipment via a series of interlocks programmed in the PLC. The interlocks will be fed by sensors internal to the safety system or from external subsystems. These interlocks determine operational parameters. For example, the fast shutter permissive transitions into the enabled state based on the state of sensors or inputs from other subsystems. Permissives do not control the device; but allows control of devices. An example is the fast shutter permissive. The fast shutter permissive goes to the enabled state when the following is true: LTCS permissive enabled, Aircraft Permissive enabled, DCS and telescope permissive enabled, operator (Observing Assistant) enabled, no faults in the system. The interlocking of the devices is shown in Figure 6. Once all the permissives are active, a command must still come from the LIS controller to open the shutter. The shutter command is also edged trigger to ensure the shutter activates only when a command is given, not while it sits at a state.

Inputs	Laser Interface System	LIS Heartback Normal	Laser System	Laser Not Faulted	Laser Enclosures Not Opened	Facility System	No Facilitity E-STOP	Bypass and Enable Switches	Fast Shutter Permissive Bypass	Fast Shutter Enable Switch	Laser Servicing Enable Switch	BTS Servicing Enable Switch	BTS System In Place	Laser Service Enclosure	LSE Enclosures Not Opened	No Laser STOP	Smoke/Fire detection Not Triggered	Beam Transfer System	Beam within Position Sensors	Laser Power Within Threshold	BTS Enclosures Closed	Fast Shutter Not Failed	Propagation System	Spotters Packs Connected	Spotters Pack NO Laser Stop	ASCAM Permissive ON	DCS Permissive ON	Boresight Camera Operational	Boresight Permissive ON	Observing Assistant Permissive ON	LTCS Permissive ON	Satellite Permissive ON
Permissives																																
Laser ON Permissive																																
Normal Operations		✓			✓		✓								✓	✓	✓															
Servicing		✓					✓				✓				✓	✓	✓															
Laser Shutter Permissive																																
Normal Operations		✓		✓															✓	✓	✓	✓										
Servicing/Alignment		✓		✓								✓										✓										
Fast Shutter Permissive																																
Normal Operation		✓		✓			✓			✓			✓			✓						✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Service		✓		✓			✓		✓	✓			✓			✓						✓										
Safe Mode Enable (All Shutters Closed)																																

Figure 6: Interlocks

5.7.1.3 Laser Status Indicators

Laser status indicators shall be provided at entry point to hazardous zones. These zones may include the LE, f/15 location and BTO interface units along the telescope structure where the laser beams are exposed by opening of a cover or entry door. The indicators will be represented in the following tables. The indicators will be momentary to minimize light contamination in the dome.

1	Laser Status Green	Acceptable to enter, no hazardous radiation
2	Laser Status Yellow	Acceptable to enter, hazardous radiation contained
3	Laser Status Red	Do not enter, hazardous radiation

Table 4: Laser Status Indicator Definition

5.7.1.4 Safety Equipment

Safety Equipment shall be provided such as infrared viewers, goggles and fire extinguishers for personnel. Goggles will be rated based on the completion of the hazard analysis. Clean Guard fire extinguishers will be used to minimize contamination of optics.

5.7.2 Administrative and Procedural Controls

Administrative and procedural controls shall be provided to ensure the system will be operated safety. Procedural controls include alignment procedures that will be provided by the subsystems. Each subsystem alignment process will be verified for safety by the Laser Safety Officer. The following is a list of alignments that will be provided by their respective subsystems:

- Laser Alignment
- Optical Switchyard Alignment
- Beam Transfer Optics Alignment
- Beam Generation System Alignment
- On-dome propagation alignment

Other procedural and administrative controls include keep out zones during alignment and confine areas for trained personnel only, such as the laser service enclosures.

5.8 Interfaces

5.8.1 Mechanical

Components of the SSC will be mounted mechanically in the AO Electronics Vault. The PLC assembly panels will be designed so they can mount directly into 19" standard electronics racks.

5.8.2 Electrical

A full list of the SSC interface can be found in KAON 753.

5.8.2.1 Laser System

The SSC will have an interface with each laser system to control the laser and receive status from the laser. The expected interface is shown in the following table. A "1" is denoted as a galvanic closure from the laser and a "0" is denoted as a galvanic open from the laser. Table 5 shows the signals for each laser.

#	Signal	Input/Output	Description
1	Emission ON	Input from laser	1 if the Laser Unit is generating laser light
2	Safety Status	Input	0 if an internal safety fault is present
3	Emergency Shutdown	Output to laser	0 to stop any light generation
4	Emergency Power Shutdown	Output	0 to shutoff power to the entire system
5	Output shutter closed	Input	1 if the output shutter is closed
6	Output shutter fault	Input	0 if there is a fault in the output shutter
7	Output shutter permissive	Output	1 to allow the output shutter to open
8	Exposed Hazardous Radiation	Input	0 if there is exposed hazardous radiation; may be represented by the "Safety Status"
9	Laser System Fault	Input	0 to denote there is an internal fault
10	Laser Interface Fault	Input	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 SSC

5.8.2.2 Laser Enclosure

The SSC will have an interface with each laser service enclosure. The laser service enclosure shall provide environmental data such as door openings for personnel safety and equipment safety. Table 6 shows signals for the laser enclosure.

#	Signal	Type	Description
1	E-Stop Activated	Input	Switch Closed = Not Activated
2	SSC Reset Activated	Input	Switch Closed = Reset
3	Door Entry Status	Input	Switch Closed = Door Closed
4	Laser1 Cabinet Status	Input	Switch Closed = Cabinet Closed
5	Laser2 Cabinet Status	Input	Switch Closed = Cabinet Closed
6	Laser3 Cabinet Status	Input	Switch Closed = Cabinet Closed
7	Smoke Alarm	Input	Switch Closed = No Alarm
8	Request for Status	Input	Switch Closed = Request
9	Glycol Flow Status	Input	Switch Closed = Flow
10	Audible Alarm	Output	24VDC = Alarm
11	Status Green	Output	24VDC = LED ON
12	Status Yellow	Output	24VDC = LED ON
13	Status Red	Output	24VDC = LED ON

14	Door LED Status	Output	24VDC = Door Unlocked
15	Shunt Trip	Output	24VDC = not tripped

Table 6: Laser Enclosure Interface

5.8.2.3 Laser Interface System

The SSC will interface with the LIS via the Keck network on the summit. The connection to the network shall be standard CAT5 cabling to the nearest network switch in the immediate area. For the node in the AO Electronics vault, it will connect to network in the vault.

The information and commands exchanged with the LIS is described in the Safety System ICD. This is the basis of the signals between the SSC and the LIS.

5.8.2.4 Laser Launch Facility

The SSC will interface with the LLF by providing status of the laser beam and environmental data. The interface will be both digital and analog I/Os.

#	Signal	Type	Description
1	Beam Positions X	Input	Calibration for 5VDC center
2	Beam Positions Y	Input	Calibration for 5VDC center
3	Beam Powers	Input	Calibration; 10VDC max power
4	LLF Cover Status	Input	Switch Closed = Cabinet Closed
5	LLF E-Stop Activated	Input	Switch Closed = Not Activated
6	LLF IN Position	Input	Switch Closed = In Position
7	Final Shutter Closed	Input	Switch Closed = Shutter NOT Closed
8	Final Shutter Opened	Input	Switch Closed = Shutter NOT Opened
9	Fast Shutter Closed	Input	Switch Closed = Shutter NOT Closed
10	Fast Shutter Open	Input	Switch Closed = Shutter NOT Opened
11	LF Request for Status	Input	Switch Closed = Request
12	Beam Dump Power	Input	Analog watts
13	LF Status Green	Output	24VDC = LED ON
14	LF Status Yellow	Output	24VDC = LED ON
15	LF Status Red	Output	24VDC = LED ON
16	Final Shutter Command	Output	1 = Open
17	Fast Shutter Command	Output	1 = Open
18	Beam Dump Insertion	Output	24VDC = Beam Dump Removed
19	Fast Shutter Command	Output	24VDC = Open

Table 7: LLF Interface

5.8.2.5 Facility System

The SSC will connect to the facility E-Stop system. The interface shall be a galvanic interface. The contact shall be normally closed to denote E-Stop not activated. The signal shall go into the computer room node from the AAA. The SSC shall also provide status for indicators for personnel going into the dome. This requirement may or may not be necessary based on how the laser system shall be operated.

#	Signal	Type	Description
1	Facility E-Stop Activated	Input	24VDC = Not activated
2	Dome Status Green	Output	24VDC = LED ON
3	Dome Status Yellow	Output	24VDC = LED ON
4	Dome Status Red	Output	24VDC = LED ON

Table 8: Facility Interface

5.8.2.6 Aircraft Permissive System

The SSC shall communicate with the Aircraft Permissive System via digital I/Os. It is unknown at this time what type of system will be used, possibly All Sky Camera (ASCAM) or other detection systems. For now, a generic system is proposed with spotter usage as a backup.

#	Signal	Type	Description
1	Aircraft Detected	Input	24VDC = No Detection
2	Detection System Operating	Input	24VDC = Operating
3	East Spotter Connected	Input	24VDC = Connected
4	East Spotter Activated	Input	24VDC = No Detection
5	West Spotter Connected	Input	24VDC = Connected
6	West Spotter Activated	Input	24VDC = No Detection

Table 9: Aircraft Detection Interface

5.8.3 Software

The SSC shall interface with the software through 16 bit words. The following table shows the data that will be transferred between the SSC and the LIS software. The data is used by the Laser User Tools such as the alarm handler and Laser Propagation Guis. The format and word number is located in the Safety System. ICD.

#	Signal	Type	Description
1	Drive and Control Permissive	Input	1=Permissive
2	Observing Assistant Permissive	Input	1=Permissive
3	Laser Traffic Control System Permissive	Input	1=Permissive
4	LCH Permissive	Input	1=Permissive

5	Telescope Elevation Permissive		
6	Laser E-Stop Command	Input	1=Activate E-STOP
7	Open Laser Shutter Command	Input	Rising Edge = Open; 0 =Close
8	Open Fast Shutter Command	Input	Rising Edge = Open; 0 =Close
9	Open Final Shutter Command	Input	Rising Edge = Open; 0 = Close
10	Reset SSC Fault Status	Input	Rising Edge = Clear
11	SSC Heartbeat Interface Fault Latch	Input	1= Latched
12	Facility E-Stop Activated Latch	Output	1= Latched
13	Laser E-Stop Activated Latch	Output	1= Latched
14	Programmable Logic Controller Fault	Output	1= Latched
15	LE Smoke Alarm Activated Latch	Output	1= Latched
16	LE1 Beam Interlock Fault Latch	Output	1= Latched
17	East Spotter Activated Latch	Output	1= Latched
18	West Spotter Activated Latch	Output	1= Latched
19	East Spotter Disconnected Latch	Output	1= Latched
20	West Spotter Disconnected Latch	Output	1= Latched
21	DCS Permissive Dropped while Propagating Latch	Output	1= Latched
22	LTCS Permissive Dropped while Propagating Latch	Output	1= Latched
23	OA Permissive Dropped while Propagating Latch	Output	1= Latched
24	LCH Permissive Dropped while Propagating Latch	Output	1= Latched
25	Telescope Permissive Dropped while Propagating Latch	Output	1= Latched
26	Laser1 Safety Status Failed Latch	Output	1= Latched
27	Laser1 Output Shutter Fault Latch	Output	1= Latched
28	Laser2 Safety Status Failed Latch	Output	1= Latched
29	Laser2 Output Shutter Fault Latch	Output	1= Latched
30	Laser3 Safety Status Failed Latch	Output	1= Latched
31	Laser3 Output Shutter Fault Latch	Output	1= Latched
32	LE/LLF Environmental Alarm Latch	Output	1= Latched
33	LLF Final Shutter Faulted Latch	Output	1= Latched
34	LLF Fast Shutter Faulted Latch	Output	1= Latched

35	LLF Beam Misalignment Fault Latch	Output	1= Latched
36	LLF Beam Power Low Fault Latch	Output	1= Latched
37	LLF Beam Interlock Fault Latch	Output	1= Latched
38	LLF Fast Shutter Status	Output	1 = Open
39	LLF Fast Shutter Permissiv	Output	1 = Permissive
40	LLF Final Shutter Status	Output	1=Open
41	LLF Final Shutter Permissive	Output	1=Permissive
42	Propagating On Sky	Output	1=On Sky Propagation

Table 10: Software Interface I/Os

5.8.3.1 Propagation Permissives

The propagation permissives from Laser Clearinghouse, LTCS, DCS, ASCAM, OA will be provided through the Laser Interface Server. These items are included in the Table 10.

5.8.3.2 Heartbeat Interface

In addition to the status and commands between the SSC and the LIS, a heartbeat interface shall be established. If communications between the SSC and LIS is stopped for a period, the SSC will automatically go into safe mode. Safe mode will automatically close the laser and final output shutters. Normal operations does not commenced until communications are established and the heartbeat fault is cleared. Safe mode is defined as closing of the fast and final shutters.

5.9 Software Configuration Management

The PLC code will be CVS per software standards. Copies of the code shall reside in a designated area and maintained by the Software Operations Group.

6 Documentation

Most of the operations documentation will be identical such as LTCS, FAA, and Laser Clearinghouse. The changes from a single beam represented by a cylinder to seven beams represented in a cone will not change current operations.

Applications for the FAA, and Laser Clearing house will be modified to account for the 7 beams.

The following procedures and data will be provided in DD phase:

- Technical Drawings
- Interlock Test Procedure
- Safety Audit Checklist
- Hazard Analysis
- Spares Recommendation

The following documentation will be provided prior to laser operations:

- Standard Operational Procedure

7 DELIVERABLES

The following chart shows the deliverables for the SSC.

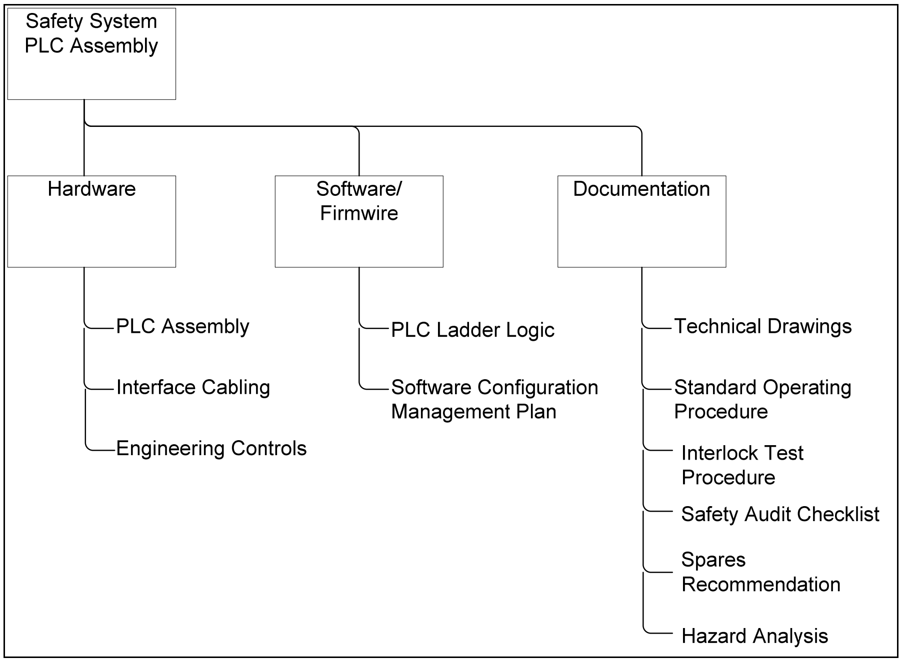

Figure 7: Safety System Deliverables

8 TESTING METHODOLOGY

8.1 Full Scale Development Phase Testing

The following provides a methodology on how the safety system will be developed and tested. More detail plans shall be provided in the Detailed Design Phase. The PLC code is developed on an Allen Bradley development platform called RsLogix500. The software runs on a standard PC. In addition to the programming platform, the RSLogix500 environment also provides an emulation mode as though the ladder logic is running on a SLC500 processor communicating to external devices. This internal testing of the user generated firmware can be done any fabrication.

Subsequent to the initial testing, the AB controller assembly and associated nodes will be fabricated. The ladder logic will then be downloaded on the PLC and run. The RSLogix500 provides a view of the inner workings of the PLC. Any fault such as arithmetic and watchdog are provided to the user. Prior to any further development of sensors or controls, the RSLogix500 software can emulate these functions to test for functionality. Interlocking and sequences should have been completed in the previous phase. This phase verifies the program is running properly on the PLC without any errors. The communications with LIS will also be verified during this phase.

Once the PLC is operating, the devices that the safety system communicates with will be fabricated and connected. The SSC will test the interfaces per the ICD. Each I/O point will be verified and interlock logics will be verified. This phase assumes the system will be operating in a laboratory environment prior to summit installation. Completion of this phase will conclude the FSD phase of the SSC. Documentation on design compliance will be provided.

8.2 Delivery and Commissioning Phase Testing

In this phase, the system and associated electronics will be moved to the summit. This phase will conclude with re-verification for the full compliance. Tests completed will be compared to those in the FSD phase.

8.3 Operational Phase Testing

In this phase, the system would have undergone full operations. Any subsequent changes will be completed under the guidance of the Change Control Board. In most circumstances, the changes will be verified without requiring full compliance testing. The following tests are recommended as part of a standard regression testing of top level functions:

- Emergency Shutdown of the System
- Fast and Final Shutters permissives
- Hazardous Laser Radiation Interlocks for the f/15 location and the Laser Service Enclosure(s)
- Environmental Status and Displays
- Laser(s) Interface

As part of maintenance, the safety system will be required to undergo periodic testing. Since the firmware has not changed, testing will focus on verification of sensors outlined in Figure 6.

9 Requirements Compliance Verification

The following table shows the SSC requirements compliance. Compliance is available in the overall LGSF Compliance Matrix. The items listed are only those in question or will be compliant in subsequent phases.

Short Name	ID	Priority	Description	Verification Method	Compliance in PD Design
Humidity Alarm(s)	FR-2116	Important	The Safety System shall provide environmental alarms that are critical to operating the laser. The alarm shall be visual and audible. The system will issue an alarm if humidity exceeded a TBD threshold in the laser operating environment. The humidity threshold will depend on the operating requirements for the laser.	Test	N/A; not required for the laser system; humidity sensing move to the controls group
Temperature Alarm(s)	FR-2115	Important	The Safety System shall provide environmental alarms that are critical to operating the laser. The alarm shall be visual and audible. The system will issue an alarm if temperature(s) exceeded a TBD threshold in the laser operating environment. The temperature will depend on the operating environment for the laser.	Test	N/A; not required for the laser system; system has self protection; temperature sensing move to the controls group
Particulate Alarm	FR-2114	Important	The Safety System shall provide environmental alarms that are critical to operating the laser. The alarm shall be visual and audible. The system will issue an alarm if particulates exceeded a TBD threshold in the laser operating environment. Typical values are Class 10,000.	Test	N/A; not required for the laser system; particulate sensing is available to ensure cleanliness
Fire Alarm System	FR-2113	Important	The Safety System shall receive status from the fire alarm system to shutdown the laser if necessary (TBD).	Test	N/A; the laser system does not require one for protection; however, a smoke alarm will be placed to support a shutdown
Hazard Labelling and Warning Signs	FR-2120	Essential	The LGS Facility shall include Hazard Labels for a Class 4 laser in accordance with ANSI Standards.	Inspection	FSD
Safety Audit Procedure	FR-2118	Essential	A checklist shall be provided for the safety auditor to perform a quarterly inspection.	Inspection	FSD
Hazard Analysis	FR-2119	Essential	A hazard evaluation shall be completed to identify Maximum Permissible Exposure limits (MPE). These will in turn determine the proper eyewear necessary to operate and maintain the laser.	Inspection	DD
Control Measures	FR-2104	Essential	Control measures shall be implemented for personnel based on MPE calculations. Protective equipment must be based on the required use for operations as well as maintenance of the laser system.	Demonstration	FSD; engineering and procedural controls are planned
Standard Operations Procedure	FR-2121	Essential	The Safety System shall provide an standard operating procedure inclusive of emergency responses, emergency contacts list, training and reporting.	Inspection	FSD
Interlock Test Procedure	FR-2117	Essential	A procedure shall be provided to test the interlocks in the Safety System. Interlock testing shall be completed on a quarterly basis to ensure the Safety System is operating safely.	Inspection	FSD

Spares Recommendation	FR-2122	Essential	A List of recommended spares with cost will be provided. Format shall be PDF or Microsoft Word.	Inspection	DD
Aircraft Permissive Signal	FR-2092	Essential	The existing Optical Electronics Incorportated (OEI) video processor shall provide a permissive signal to the Laser Safety System to allow or disallow propagation of the laser beam out of the telescope.	Test	N/A; not required for FAA

Table 11: Compliance Status

10 MANAGEMENT

10.1 Risk Assessment

Based on the risk guidelines of KAON 510, the risks associated with the laser safety system as a whole is low. The following table shows individual risks within SSC, their ranking and mitigation plans if necessary.

Table 12 shows individual risks within SSC in accordance with KAON 510.

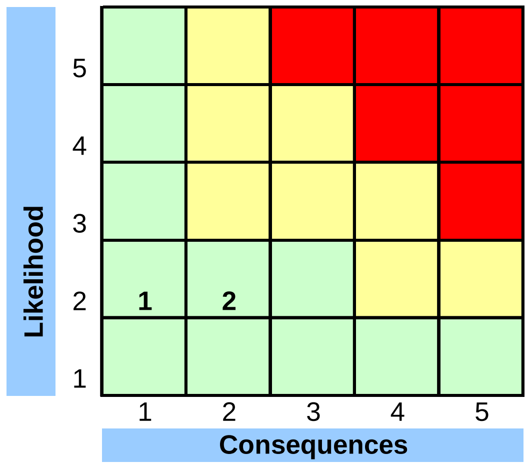

Table 12: Risk Matrix

#	Consequence	Likelyhood	Description	Status	Mitigation
1	1	2	I/O growth	Significant growth of the number of I/Os may increase the size of the PLC	Currently, there are two additional slots that can accommodate 64 spare channels as designed by the Keck 1 system.
2	2	2	No room in the AO e-vault for PLC assembly	The AO e-vault enclosure is not fully developed.	AB has a node system which will remove this issue; but the cost and complexity of the system will increase.

Table 13: Risk Analysis

10.1.1 Input / Output Growth

Currently, not all the designs have been established, thus some growth may be expected as the designs evolved. The current Keck I PLC, for example has sufficient spares for two additional modules to support an additional 64 digital I/Os.

10.1.2 Volume in the AO e-vault

The e-vault design has not been established. Once it is complete, this risk can be put to rest. The fall back is to use a node type configuration with part of the PLC elsewhere, such as the computer room where more volume is available. This is a typical AB approach in terms of low risk; but will increase the overall cost. There may be some savings as cables can be shorter and will not have to be routed in the telescope.

10.2 Budget

The effort and procurements estimates are provided below for the Safety System Controller Assembly

Category	**DD**	**FSD**	**DC**
AssoSci	248	420	200
Technician	78	330	222
LeadSci	160	176	128
ProjMgr	8	4	4
Subtotal	494	930	554
Total (hours)			**1978**

Table 14: SSC Effort Estimates (Hour)

Procurements	Input Code	Estimate	Cost $
Processor	EQP	CP	$6,000.00
Chassis	EQP	CP	$500.00
Comms Interface	EQP	CP	$1,700.00
Analog Interface	EQP	CP	$1,200.00
Temperature Interface	EQP	CP	$1,000.00
Digital Interface	EQP	CP	$1,200.00
Power Supplies	EQP	EE	$3,000.00
Assembly Hardware	MAT	EE	$2,000.00
Safety Equipment	EQP	EE	$5,000.00
Panels	MAT	EE	$1,500.00
Cables and Connectors	MAT	EE	$3,000.00
AKCP Unit	EQP	CP	$1,500.00
Electronics Rack	EQP	CP	$3,500.00
Installation Hardware	MAT	EE	$1000.00
Total			**$32,100.00**

Table 15: Procurements

10.3 Schedule

WBS	Task Name	Start	Finish
1	**NGAO Safety System Controller DC (SS, WBS 5.4.1)**	**Fri 10/1/10**	**Wed 11/4/15**
1.1	**Project Management & Reviews**	**Fri 10/1/10**	**Wed 8/13/14**
1.2	**Detailed Design Phase**	**Fri 10/1/10**	**Fri 9/28/12**
1.2.1	DD Phase Planning and Reporting	Fri 10/1/10	Wed 5/23/12
1.2.2	**Engineering Tasks**	**Fri 10/1/10**	**Fri 11/12/10**
1.2.2.1	**PLC Assembly**	**Fri 10/1/10**	**Fri 11/12/10**
1.2.2.1.1	Layout and Infrastructure	Fri 10/1/10	Fri 10/8/10
1.2.2.1.2	Electronics Drawings	Mon 10/11/10	Mon 10/18/10
1.2.2.1.3	Interface Design	Tue 10/19/10	Mon 11/1/10
1.2.2.1.4	Firmware	Tue 11/2/10	Fri 11/5/10
1.2.2.1.5	Software Interface	Mon 11/8/10	Fri 11/12/10
1.2.2.2	AO Environmental Monitoring	Fri 10/1/10	Wed 10/20/10
1.2.2.3	Integration and Test Plans	Fri 10/1/10	Tue 10/5/10
1.2.3	**System Engineering Tasks**	**Mon 11/15/10**	**Fri 9/28/12**
1.3	**Full Scale Development Phase**	**Wed 5/23/12**	**Tue 5/13/14**
1.3.1	FSD Phase Planning and Reporting	Wed 5/23/12	Tue 5/13/14
1.3.2	**Engineering Tasks**	**Wed 5/23/12**	**Fri 10/5/12**
1.3.2.1	**PLC Assembly**	**Wed 5/23/12**	**Tue 9/4/12**
1.3.2.1.1	Layout and Infrastructure	Wed 5/23/12	Tue 6/19/12
1.3.2.1.2	Assembly	Tue 6/19/12	Wed 7/4/12
1.3.2.1.3	Interface Fabrication	Wed 7/4/12	Wed 8/1/12
1.3.2.1.4	Electronics Drawings Update	Wed 8/1/12	Wed 8/15/12
1.3.2.1.5	Firmware	Wed 8/15/12	Tue 8/21/12
1.3.2.1.6	Software Interface	Tue 8/21/12	Tue 9/4/12
1.3.2.2	AO Environmental Monitoring	Tue 9/4/12	Fri 9/14/12
1.3.2.3	Testing and Verification	Fri 9/14/12	Fri 9/28/12
1.3.2.4	Safety Procedures	Fri 9/28/12	Fri 10/5/12
1.3.3	**System Engineering Tasks**	**Fri 10/5/12**	**Fri 9/27/13**
1.4	**Delivery and Commissioning Phase**	**Tue 5/13/14**	**Wed 11/4/15**
1.4.1	DC Phase Planning and Reporting	Tue 5/13/14	Wed 11/4/15
1.4.2	**Engineering Tasks**	**Tue 5/13/14**	**Tue 7/22/14**
1.4.2.1	Packing at HQ; unpack at summit	Tue 5/13/14	Wed 5/14/14
1.4.2.2	**Installation**	**Wed 5/14/14**	**Tue 7/1/14**
1.4.2.3	**Testing and Verification**	**Tue 7/1/14**	**Wed 7/16/14**
1.4.2.4	Operational Procedures	Thu 7/17/14	Tue 7/22/14
1.4.3	**System Engineering Tasks**	**Tue 7/22/14**	**Wed 8/13/14**

Figure 8: SSC Schedule

11 Plans for the next Phase

The following effort is planned for the Detailed Design Phase:

- Completed designs and fabrication drawings
- Software keywords definition
- Completed Interface Control Document
- Implementation and test plans
- Operational and Maintenance Plans
- Handover Plans
- Spares Recommendation
- Retirement of risks
- Budget and Schedule