Requirements for

MOSFIRE: MULTI-OBJECT SPECTROMETER FOR INFRA-RED EXPLORATION

Version 1.4
April 15, 2007

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Figures and Tables

1 INTRODUCTION

This document describes the requirements for MOSFIRE, a cryogenic multi-object near-infrared spectrometer for the Keck I telescope at the W. M. Keck Observatory (WMKO).

MOSFIRE will provide near-IR (~0.97 to 2.45 μm) imaging and multi-object spectroscopy over a 6.14' x 6.14' field of view with a resolving power of R~3,270 for a 0.7" slit width (R~4800 for a 0.5" slit), or imaging over a field of view (FOV) of 6.14' with 0.18" per pixel sampling. Using a single state-of-the-art Rockwell Hawaii-2RG HgCdTe detector with 2K x 2K pixels, MOSFIRE will capture most or all of an atmospheric window in a *single* exposure for any slit placed within a 6.12' x 3' field, and the instrument will employ a single diffraction grating used in multiple orders (3, 4, 5, and 6) for dispersion in the K, H, J and Y (a.k.a. Z) bands, respectively. The grating is deployable at two discrete angles located by fixed stops providing a small position shift for spectra on the detector in order to maximize wavelength coverage for K and H at one position and J and Y at the other position.

A special feature of MOSFIRE is that its multiplex advantage of up to 46 slits is achieved using a cryogenic configurable slit unit (CSU) being developed in collaboration with the Swiss Centre for Electronics and Microtechnology (CSEM). The CSU is reconfigurable under remote control in less than 5 minutes without any thermal cycling of the instrument.

MOSFIRE is being developed for WMKO by the University of California, Los Angeles (UCLA), the California Institute of Technology (CIT) and the University of California, Santa Cruz, (UCSC). The MOSFIRE Co-Principal Investigators are Ian McLean of UCLA and Charles Steidel (CIT).

The requirements in this document are finalized based on completion of the detailed design phase of the instrument and these requirements now form the basis of the acceptance test criteria for the instrument. The requirements continue to carry goal values for parameters whose final values will be determined only when fabrication is complete. Where goal parameters remain they are accompanied by worst case (maximum or minimum as appropriate) values.

The purpose of a requirements document is to define and communicate the Observatory's expectations for the design and implementation of a new scientific instrument for the Observatory. As the procuring organization, WMKO authors the requirements document in collaboration with the instrument design team.

A requirements document describes the new instrument in terms of the needed scientific and technical performance. The document also expresses specific requirements for implementation or design where those requirements are essential to satisfactory integration and interoperation of the instrument with the observatory systems. The requirements document also references consensus standards approved by recognized standards organizations for specific guidance on technical matters related to implementation, compatibility and safety.

The document avoids prescribing specific design or implementation solutions except for solutions that embody the Observatory's unique knowledge or experience. The document establishes requirements for the new instrument that will guide the design of the instrument through the detailed design phase.

2 SCOPE AND APPLICABILITY

This document establishes requirements for all aspects of MOSFIRE. This document also establishes requirements for changes to related sub-systems and software of the Keck I telescope where required.

This revision of the document is the final design phase release.

3 REFERENCES

3.1 Related Documents

1. Spanoudakis, P. et al. "MOSFIRE Configurable Slit Mask Unit, CSU Design and Analysis Report", RSM.CSE.RP01 Issue 2 Rev. A. March 23, 2007. CSEM Project No: 211-IN.0400. Swiss Centre for Electronics and Microtechnology (CSEM) CH-2007 Neuchâtel, Switzerland.

2. "Interface Control Document for MOSFIRE: Multi-Object Spectrometer For Infra-Red Exploration, Version 1.3". April 12, 2007 W. M. Keck Observatory. April 12, 2007.

3. Greisen, E.W. and Calabretta, M.R. "Representations of world coordinates in FITS" 2002 A&A, 395, 1061

4. Calabretta, M.R. and Greisen, E.W. "Representations of celestial coordinates in FITS" 2002 A&A, 395, 1077

5. Greisen, E.W., Calabretta, M.R., Valdes, F.G., and Allen, S.L. "Representations of spectral coordinates in FITS" 2006 A&A, 446, 747

3.2 Referenced Standards

3.2.1 Industry Consensus Standards

Table 1 lists the industry consensus standards referenced in this document in alphabetical order by standardizing organization. Unless otherwise noted all references to standards are included because compliance with some part of each standard is required.

Table 1: Referenced Standards

Source (Organization or Standardizing Body)	Number	Title
ANSI	Y14.5M-1994 (R1999)	Dimensioning and Tolerancing
ANSI	Y14.1-1995 (R2002)	Decimal Inch Drawing Sheet Size And Format
ANSI	Y14.34-2003	Parts Lists, Data Lists, And Index Lists: Associated Lists
ANSI	Y14.3M-1994	Multi And Sectional View Drawings
ANSI / ASME	Y14.18M-1986	Optical Parts (Engineering Drawings and Related Documentation Practices)
ASME	HPS-2003	High Pressure Systems
ASME	Y14.100-2000	Engineering Drawing Practices
ASME	Y32.10-1967 (R1994)	Graphic Symbols for Fluid Power Diagrams
ASTM	E595-93 (2003)e1	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
ATA	Spec 300-2001.1	Specification for Packaging of Airline Supplies
CENELEC	EN 50082-1:1997[1]	Electromagnetic compatibility – Generic immunity standard – Part 1: Residential, commercial and light industry
Council of the European Communities	EMC 89/336/EEC[1]	Council Directive 89/336/EEC of 3 May 1989 on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive)
County of Hawaii	1995 edition	Hawaii County Code 1983 (1995 edition)
Department of Defense	MIL- STD-171E	Finishing of Metal and Wood Surfaces
Department of Defense	MIL-HDBK-217F-2[1]	Reliability Prediction of Electronic Equipment
Department of Defense	MIL-STD-810F	Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
EIA	EIA-310-D	Cabinets, Racks, Panels, and Associated Equipment
EIA	EIA-649[1]	National Consensus Standard For Configuration Management
EIA	EIA RS-232-C, August 1969	EIA Standard RS-232-C Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Data Interchange

1. This reference for information only.

Table 1: Referenced Standards, continued

Source (Organization or Standardizing Body)	Number	Title
FCC	Title 47 CFR Part 15[1]	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)
IEEE	1012-2004	Standard for Software Verification and Validation
International Code Council (ICC)	IBC-2006	2006 International Building Code®
ISO/IEC	ISO / IEC 12207:1995	Information Technology - Software life cycle processes
National Electric Manufacturers Association	250-1997	Enclosures for Electrical Equipment (1000 Volts Maximum)
National Fire Protection Association (NFPA)	NFPA 55, 2005 edition	Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks
NFPA	NFPA 70, 2005 edition	National Electric Code
NFPA	NFPA 99C, 2005 edition	Standard on Gas and Vacuum Systems
Naval Surface Warfare Center	NSWC 98/LE1[1]	Handbook of Reliability Prediction Procedures for Mechanical Equipment
OSHA	Title 29 CFR Part 1910	Occupational Safety And Health Standards
Telcordia	GR-63-CORE	NEBS™ Requirements
TIA/EIA	TIA/EIA-568-B	Commercial Building Telecommunications Cabling Standards
Underwriters Laboratories Inc.	Standard for Safety 508	Industrial Control Equipment

1. This reference for information only.

3.2.2 WMKO Standards

WMKO software standards are also referenced in this document. References to these standards are included because compliance with some part of each standard may be required.

Table 2: WMKO Standards

Source (Organization or Standardizing Body)	Number	Title
WMKO	KSD 3	Software Items for Acceptance Review
WMKO	KSD 8	KTL: the Keck Task Library
WMKO	KSD 46a	DCS Keyword Reference Manual (partial)
WMKO	KSD 50	Keck II C Style and Coding Standards
WMKO	KSD 201	How to Set Up a config.mk Build
WMKO	KSD 210	WMKO Software Standards

3.3 Referenced Drawings

Table 3 lists the drawing numbers, revisions and date, source and title for all drawings referenced in this document.

Table 3: Referenced Drawings

Drawing #	Revision/Date	Source	Title
1000-C0013	None/8-15-96	WMKO	Cassegrain Instrument Interface Envelope Keck II/I
1085-C0100	A/*	WMKO	Keck I Cassegrain MOSFIRE Instrument Interface
1201-C1200	A/*	WMKO	Keck I Nasmyth Deck MOSFIRE Instrument Interface, RT1 Position
1085-C1203	A/*	WMKO	Keck I Nasmyth Deck Instrument Interface, RT1 Position
199-06-04	B	TIW	Defining Point Mechanism W. M. Keck Telescope
640-C0011	D/2-10-05	WMKO	Keck I Instrument Stowage Layout
110-10-07	C/6-12-03	WMKO	Keck I Telescope Travel Limits
115-05-00	C/3-31-07	WMKO	MOSFIRE One Line Diagram

* = in progress, drawing to be issued

4 REVISION HISTORY

Version	Date	Author	Reason for revision / remarks
0.1	March 26, 2006	SMA	Original Issue
1.0	March 30, 2006	SMA	Incorporate comments
1.1	April 3, 2006	SMA	Add glycol parameters, vacuum fittings, fix references in section 12
1.2	April 4, 2006	SMA	Add host computer and data storage requirements
1.3	September 11, 2006	SMA	Incorporate WMKO and other comments
1.4	April 15, 2007	SMA	DDR Release

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5 BACKGROUND

5.1 Purpose

The purpose of the background section of this document is to provide context and related information for the requirements defined in later sections of this document.

5.2 Motivation for the Development of MOSFIRE

Multi-object spectrometers (MOSs) are required to understand object populations. The Keck community has already used the single object near-IR spectrometer NIRSPEC to study many young stars, galactic center objects, high redshift galaxies, and star formation in obscured galaxies. These observations have revealed much about the properties of small numbers of these objects, including numerous important and unique discoveries. However, detailed knowledge about object populations will elude us until we have hundreds or thousands of near-IR spectra of these objects, spanning a variety of environments, physical conditions, etc. Many of the most exciting applications of near-IR spectroscopy are the most difficult, and will require extremely long integration times even with a 10 m aperture; the ability to observe many objects at once will make such challenging observations feasible for the first time. The Keck Observatory needs a new near-IR MOS in order to pursue such studies.

MOSFIRE is being designed as a Cassegrain instrument for the Keck I telescope because of the current imbalance in demand for observing time between the two telescopes. MOSFIRE on Keck I will help in achieving a better balance between Keck II and Keck I.

5.3 Overview

5.4 System Overview

The scientific and technical requirements for MOSFIRE result in the following basic system components:

1. An optical system to relay the required field of view onto the science detector and a dispersion system capable of achieving the required resolving power
2. A vacuum-cryogenic dewar to contain the opto-mechanical system
3. An opto-mechanical system consisting of:
    a. A support structure for the optical system
    b. A cryogenic cooling system capable of reaching operating temperatures of 120 K to 130 K
    c. A CSU with up to 46 slits
    d. Mechanisms for selection of filters and imaging or spectroscopic mode
    e. An internal flexure compensation system
    f. A cable wrap

4. An instrument rotator
5. An instrument handler system for installation in the Cassegrain focal station
6. Electronics consisting of:
    a. An IR detector system
    b. Dewar temperature and pressure monitoring
    c. Motion control systems for all mechanisms
    d. An external optical guider system
7. Instrument control software
8. A data reduction pipeline
9. Interfaces to the telescope and observatory systems

5.4.1 MOSFIRE Instrument Layout and Constraints

A sectioned side view of the MOSFIRE instrument in at the end of the detailed design stage is shown in Figure 1. MOSFIRE is designed for mounting at the Cassegrain position of the Keck I telescope. This focal station imposes strict envelope requirements as well as requirements to cope with varying gravity vectors during operation. The Cassegrain position also requires that the instrument meet specific weight and balance requirements and provide definition points compatible with the existing defining points used for the LRIS instrument on Keck I.

5.4.2 MOSFIRE Operating Modes

MOSFIRE provides both imaging and spectrometer modes of operation. The relative fields of view for the two operating modes are illustrated in Figure 2. The field of view for imaging is established by the detector, which covers an areas of 6.14' x 6.14' indicated by the red square, in the 6.8' diameter optical FOV indicated by the blue circle.

The green rectangle indicates a possible mask layout for multi-object spectroscopy over an area of 6.1' x 4'. The spectral coverage obtained is a function of the slit position within the FOV. Two grating positions are provided in order to maximize the single exposure spectral coverage in each wavelength band for slits located over at least the central 3' of the spectrometer FOV in the spectral dispersion direction.

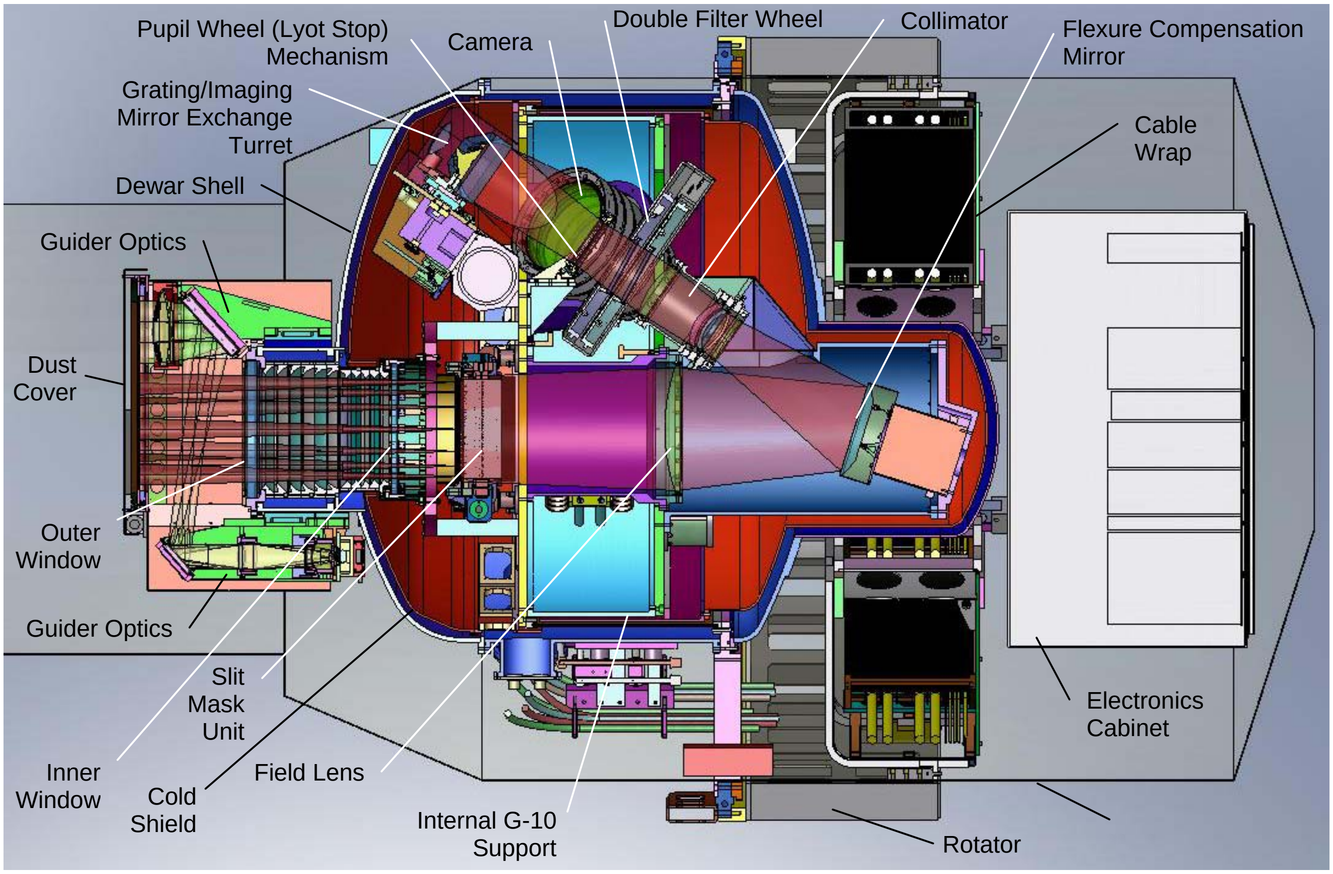

Figure 1: Section view of MOSFIRE.

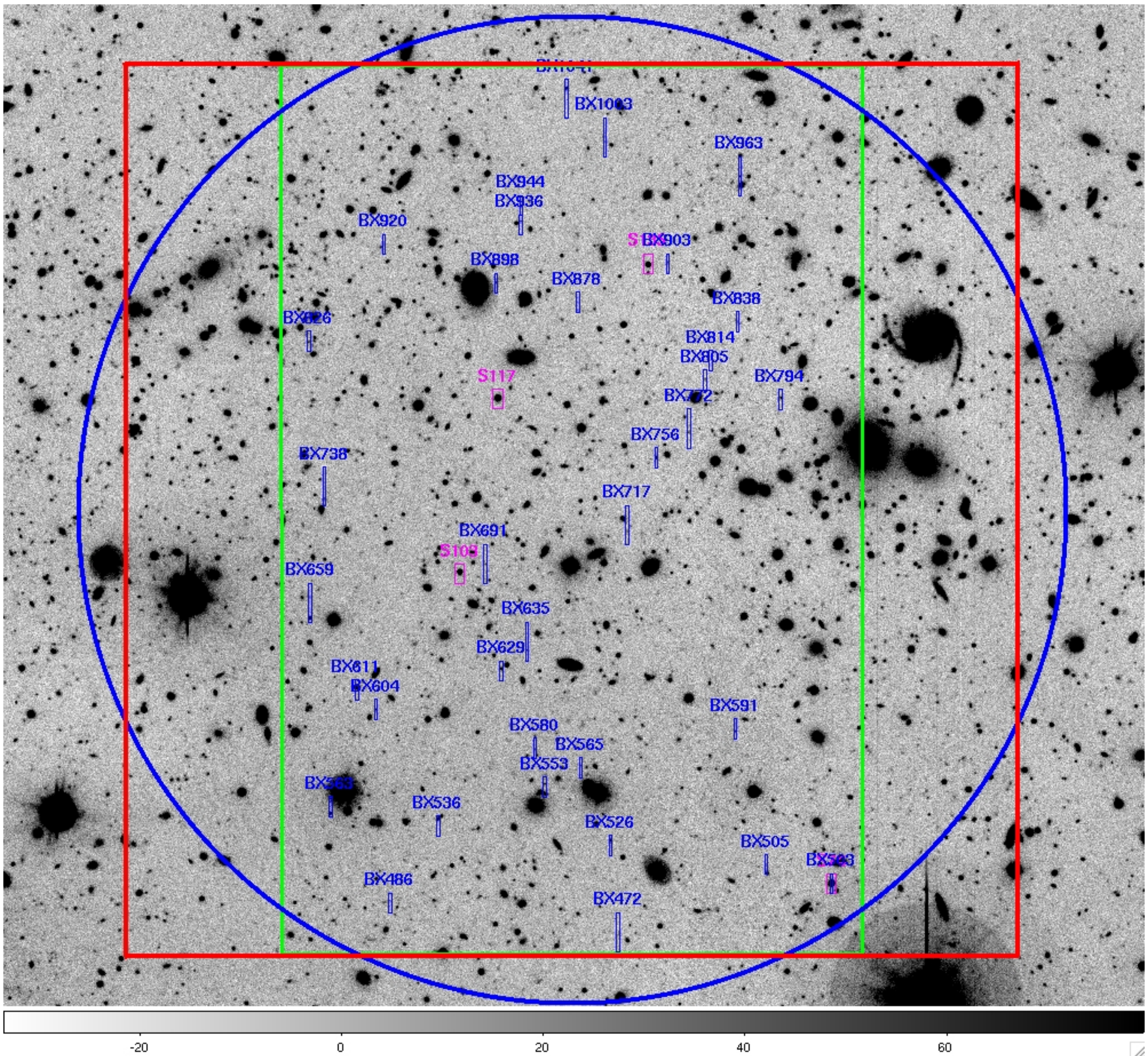

Figure 2: Example MOSFIRE Field of View

5.5 MOSFIRE Glossary

In the descriptions that follow and in all other project documentation it is recommended that the following names and definitions for the components of MOSFIRE be adopted:

MOSFIRE: the complete system consisting of the MOSFIRE Instrument, handler and associated computers, private network, software and accessories.

MOSFIRE Instrument: the telescope-mounted portion of MOSFIRE consisting of the dewar, cable wrap, electronics racks and rotator.

Dewar: a vacuum cryostat chamber containing the science optical path, configurable slit mask unit, science detector and associated components.

Instrument Cable Wrap: a structure attached to the rear of the dewar to allow connections between the stationary telescope interface panel and the instrument mounted in the rotator.

Instrument Electronics Cabinet: a welded aluminum cabinet meeting the NEMA-4 specification that provides two bays equipped with EIA 19 inch rack mounting rails. Each bay has 25 U (43.75 inches) of rack panel space. The electronics cabinet is located at the rear of the MOSFIRE instrument behind the cable wrap.

Handler: the support and handling structure for MOSFIRE. The handler travels on a rail system integral to the Cassegrain platform and Nasmyth deck of Keck I. The handler is moved using a detachable tractor assembly.

Rotator: the rotator is a structure in which the dewar, cable wrap and electronics racks are mounted and which rotates the dewar, cable wrap and electronics racks about the telescope's optical axis in order to compensate for the image rotation that occurs as the telescope follows the sidereal motion of the sky.

MOSFIRE Guider: MOSFIRE is equipped with an off axis guider mounted adjacent to the main dewar window. The guider consists of two major subsystems, the optics and the camera. The optics are custom designed and built as part of the MOSFIRE project. The guide camera will be the SciMeasure Little Joe camera selected for the Observatory's new guider system MAGIQ.

MOSFIRE computer: a computer dedicated to providing software functions for MOSFIRE. There will be two or more of these, and they are divided into two broad categories, host and target. MOSFIRE will use a client-server architecture. Low-level servers implement Keck keyword communications for clients and low level interfaces to instrument hardware to allow keyword control of the instrument. A global server is used to coordinate keyword activities by multiple low level servers. Low-level server applications can run on either the host computer or a target computer. Low-level servers that demand significant amounts of processor resources are often deployed on dedicated computers, these are commonly called target computers. The host computer is the computer where the user interface applications are run, even though this same computer may also run on or more of the server applications as well.

MOSFIRE target computer: a computer dedicated to running one or more low-level server applications that provide keyword control of MOSFIRE hardware systems. A target computer has one or more hardware interfaces to subsystems of the instrument such as detectors or mechanism motion control.

MOSFIRE host computer: the computer where the MOSFIRE global server and user interface software is run.

MOSFIRE Computer Rack: an EIA 19 inch rack located in the Keck I computer room and housing the MOSFIRE computers, data storage disk array, private network interfaces and related components.

6 OVERALL REQUIREMENTS

6.1 Purpose and Objectives

The purpose of the overall requirements section is to convey requirements that apply generally to the overall instrument and its accessories.

6.2 Performance Requirements

6.2.1 Parametric Performance Requirements

6.2.1.1.1 Transportation and Shipping Environment

When packaged as required in §6.3.2.1 MOSFIRE 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 4.

Table 4: 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.

6.2.1.1.2 Non-Operating Environment

MOSFIRE 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 Table 5. 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	-	-	8.0×10^{-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.

6.2.1.1.3 Operating Environment

The operating environment is the ensemble of all conditions experienced under normal telescope operation when the MOSFIRE Instrument is installed at the Keck I telescope Cassegrain position. All performance requirements shall be met while MOSFIRE Instrument is subjected to the operating environment conditions given in Table 6.

Table 6: 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.

6.2.2 Operational Performance Requirements

6.2.2.1 Air Borne Contaminants

The weather conditions at the summit of Mauna Kea include frequent high winds resulting in some air borne contaminants, particularly dust and insects. Instruments must be protected during installation and handling against the entry of these contaminants, in particular care must be taken with optical surfaces, precision mechanisms and fine pitch or fiber optic connectors.

6.2.2.2 Audible Noise

Unless otherwise specified or accepted MOSFIRE and any pumps, motors, outboard electronics or computers should not at any time produce audible noise in excess of 50 dBA at a distance of 1 meter. This is a standard office operating environment maximum noise level. This includes intermittent noises from pumps and variable speed cooling fans. Audible warning signals for emergency or fault conditions are exempt from this requirement, but they must be provided with a silence after delay feature or a manual silencing switch.

6.2.2.3 Telescope Reconfiguration

MOSFIRE should be designed to facilitate telescope reconfigurations by allowing complete disconnection of all instrument services when the instrument is to be moved during telescope reconfigurations. This includes all power and control signals, glycol and closed cycle refrigerator (CCR) helium lines. It is essential that the instrument be able to return to operation without requiring special procedures or maintenance provided that the total elapsed time of the disconnection does not exceed a specified duration. This specified duration shall be at least 30 minutes. The thermal design of the instrument should be such that the shortest practical time is required to return to normal operating temperature.

The instrument control system and software should incorporate provisions for quick restart of temperature control and other essential housekeeping functions.

6.2.2.4 Power Failure Tolerance

The observatory summit facilities provide backup power to the instrument electronics. The first level of backup is the Keck I dome UPS, an industrial uninterruptible power supply (UPS) shared with the other instruments on Keck I. This UPS has a hold up time of 30 minutes. A separate UPS is provided for the Keck I computer room, and this UPS provides backup power for the instrument computers. The Keck I computer room UPS also has a hold up time of 30 minutes.

Under normal conditions the Observatory summit standby generator will start within 1 minute of the power failure and begin supplying primary power to the Keck I dome UPS, Keck I computer room UPS and the other UPS units at the summit.

During a power failure the glycol cooling system pumps and chiller will be inoperative, so instrument electronics dependent on glycol cooling require either flow switches or temperature sensors to ensure that the electronics are shut down even though the electronics will be powered from the Keck I dome UPS and the Observatory summit standby generator.

The CCR compressors and CCR heads are powered from the generator but they require glycol cooling for continuous operation. During a power failure the CCR compressors will experience momentary power interruptions of less than 1 minute duration and will then continue to operate on the generator until their thermal protection systems shut them down.

Under normal conditions the Observatory summit standby generator has sufficient fuel for 18 hours of continuous operation at full load. With only two exceptions in over 10 years of operation, the longest power failures to date that WMKO has experienced at the summit have been less than 1 hour in duration.

The worst-case conditions to be experienced by the instrument can be understood to occur under conditions where the Observatory summit standby generator fails to start. In this case the CCR compressors and CCR heads will cease to operate, and within 30 minutes the dome UPS and computer room UPS will be exhausted resulting in a total instrument power failure for a further 30 minutes based on the majority of the worst case power failures to date.

Because of the possibility of power failures, and also the necessity of disconnecting instruments from services during telescope reconfiguration, instruments should be designed so that power failures of up to 1 hour in duration affecting the electronics, glycol cooling and CCR systems will not degrade the performance of the instrument or damage any components. It is highly desirable that the instrument tolerates the longest possible power failure duration. The limit of power failure duration is defined as the longest time that an instrument initially at operating temperature can go without power before maintenance procedures such as pumping are required to return to normal operation.

6.3 Implementation Requirements

None.

6.3.1 Common Practice Implementation Requirements

None.

6.3.2 Standards Implementation Requirements

6.3.2.1 Shipping Containers

All shipping containers must be designed to provide adequate protection for the equipment during transport. Unless otherwise specified single use containers suitable for the size, weight and shipment method to be employed are acceptable. For guidance in the design of suitable containers consult Air Transport Association (ATA) Spec 300, 2001.1 edition, “Specification for Packaging of Airline Supplies”.

6.3.3 Regulatory Implementation Requirements

MOSFIRE shall comply in all respects with the applicable requirements of the Occupational Safety and Health Administration (OSHA) as established by Code of Federal Regulations (CFR) 29 Part 1910 “Occupational Safety And Health Standards”, particularly subpart O, section 1910.212 and subpart S sections 1910.302 through 1910.304.

The requirements of Subpart O, section 1910.212 that are applicable to MOSFIRE are summarized as follows:

1. *Machine guarding must be provided to protect the operator and other employees from hazards such as those created by ingoing nip points or rotating parts.*
2. *Guards shall be affixed to the machine.*
3. *Revolving barrels and drums shall be guarded by an enclosure that is interlocked with the drive mechanism so that the barrel or drum cannot revolve unless the guard is in place.*

The requirements of Subpart S, sections 1910.302 through 1910.304 that are applicable to MOSFIRE may be summarized as follows:

1. *Listed or labeled equipment shall be used or installed in accordance with any instructions included in the listing or labeling.*
2. *Conductors shall be spliced or joined with splicing devices suitable for the use or by brazing, welding, or soldering with a fusible metal or alloy. Soldered splices shall first be so spliced or joined as to be mechanically and electrically secure without solder and then soldered. All splices and joints and the free ends of conductors shall be covered with insulation equivalent to that of the conductors or with an insulating device suitable for the purpose.*
3. *Parts of electric equipment which in ordinary operation produce arcs, sparks, flames, or molten metal shall be enclosed or separated and isolated from all combustible material.*
4. *Electrical equipment may not be used unless the manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product may be identified is placed on the equipment. Other markings shall be provided giving voltage, current, wattage, or other ratings as necessary. The marking shall be of sufficient durability to withstand the environment involved.*
5. *Each disconnecting means for motors and appliances shall be legibly marked to indicate its purpose, unless located and arranged so the purpose is evident.*
6. *Live parts of electric equipment operating at 50 volts or more shall be guarded against accidental contact by approved cabinets or other forms of approved enclosures.*
7. *A conductor used as a grounded conductor shall be identifiable and distinguishable from all other conductors. A conductor used as an equipment grounding conductor shall be identifiable and distinguishable from all other conductors.*
8. *No grounded conductor may be attached to any terminal or lead so as to reverse designated polarity.*
9. *A grounding terminal or grounding-type device on a receptacle, cord connector, or attachment plug may not be used for purposes other than grounding.*
10. *Conductors and equipment shall be protected from overcurrent in accordance with their ability to safely conduct current.*
11. *Overcurrent devices may not interrupt the continuity of the grounded conductor unless all conductors of the circuit are opened simultaneously.*
12. *Overcurrent devices shall be readily accessible to each employee or authorized building management personnel. These overcurrent devices may not be located where they will be exposed neither to physical damage nor in the vicinity of easily ignitable material.*
13. *Fuses and circuit breakers shall be so located or shielded that employees will not be burned or otherwise injured by their operation due to arcing or suddenly moving parts.*
14. *Circuit breakers shall clearly indicate whether they are in the open (off) or closed (on) position.*
15. *The path to ground from circuits, equipment, and enclosures shall be permanent and continuous.*

16. *Metal enclosures for conductors shall be grounded.*
17. *Exposed, non-current-carrying metal parts of fixed equipment, which may become energized, shall be grounded.*
18. *Exposed non-current-carrying metal parts of cord and plug connected equipment, which may become energized, shall be grounded.*
19. *Non-current-carrying metal parts of fixed equipment, if required to be grounded, shall be grounded by an equipment grounding conductor, which is contained within the same raceway, cable, or cord, or runs with or encloses the circuit conductors. For DC circuits only, the equipment grounding conductor may be run separately from the circuit conductors.*

For the purposes of the foregoing approved means acceptable to the authority enforcing the applicable subpart. The authority enforcing the applicable subpart is the Assistant Secretary of Labor for Occupational Safety and Health. The definition of ''acceptable'' indicates what is acceptable to the Assistant Secretary of Labor, and therefore approved within the meaning of the applicable subpart. Approved for the purpose means approved a specific purpose, environment, or application described in a particular standard requirement. Suitability of equipment or materials for a specific purpose, environment or application may be determined by a nationally recognized testing laboratory, inspection agency or other organization concerned with product evaluation as part of its listing and labeling program.

Note that the preceding text is reproduced verbatim from the referenced CFR and any grammatical errors or typographical errors are part of that text.

6.4 Design Requirements

6.4.1 Technological Design Requirements

6.4.1.1 Materials Suitability and Safety

Certain environmental conditions (low temperature and pressure) at the summit of Mauna Kea make certain materials unsuitable for use in instrument construction. Materials used in the construction, lubrication or packaging of instruments 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 MOSFIRE.

Table 7 lists specific materials that should not be used. Note that this table applies to portions of the instrument normally open to the atmosphere. See §8.4.1.1 for materials considerations for vacuum cryostats and similar environments.

Table 7: 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.

6.4.2 Regulatory Design Requirements

None.

6.4.3 Standards Related Design Requirements

None.

6.4.4 Integration Related Design Requirements

None.

7 OPTICAL REQUIREMENTS

7.1 Purpose and Objectives

The purpose of this section is to describe requirements for the performance, implementation and design of the MOSFIRE optical system. In many cases these requirements are derived directly from the construction optical design of the instrument.

Optical parametric performance requirements for MOSFIRE are grouped into two categories, typical parameters and goal parameters. Requirements for typical parameters are given where enough is known to establish a range of values for the listed parameters. Requirements for goal parameters are given where scientific or technical uncertainty prevents a full definition of the achievable range of values for the listed parameters. Minimum and maximum values for are provided for all goal parameters in order to indicate the acceptable bounds on worst-case performance.

7.2 Performance Requirements

7.2.1 Parametric Performance Requirements

7.2.1.1 Typical Parameters

MOSFIRE should provide the optical performance described in Table 8.

Table 8: MOSFIRE Typical Optical Performance Requirements

Parameter	*Min.*	*Typ.*	*Max.*	*Units*	*Notes*
FOV					
Imaging	6.14 x 6.14	-	-	arc minutes	
Multi-object spectroscopy	6.12 x 3.00	-	-	arc minutes	1
Wavelength coverage					
Y-band	0.95	-	1.05	µm	2
J-band	1.1	-	1.4	µm	2
H-band	1.475	-	1.825	µm	2
K-band	2	-	2.45	µm	2,4
Imaging plate scale	-	0.18	-	arc seconds/pixel	
Spectral resolution					
Multi-object spectroscopy					
0.7” slit width	-	3,270	-	$\lambda/\Delta\lambda$	
0.36” slit width	-	4,800	-	$\lambda/\Delta\lambda$	
Input focal ratio	-	*f*/15	-	n/a	
Science detector	n/a	2048 x 2048	n/a	X by Y pixels	
Guider					
FOV	2.8 x 2.8	-	-	arc minutes	
Sensitivity	18	-	-	V mag.	3

Notes:

1. Slits can be placed anywhere within the imaging FOV. Maximum spectral coverage in each wavelength band is obtained for slits located in the spectral dispersion direction over the central 3' of the imaging FOV.
2. Imaging and spectroscopy.
3. For a SNR of 10, assuming a CCD47-20BT CCD, RG780 filter and a total throughput (telescope + guider optics) of 35%.
4. The long wavelength value quoted here is beyond the end of the K-band, but is stated to reflect the values used in the optical design analysis. The exact cutoff will be determined by the filter choices.

7.2.1.2 Goal Parameters

The optical performance requirements shown in Table 9 are desired as design goals.

Table 9: MOSFIRE Goal Optical Performance Requirements

Parameter	*Goal*	*Min.*	*Max.*	*Units*	*Notes*
Image quality					
Imaging	< 0.25	-	0.30	arc seconds	1,3
Spectroscopy	> 80	75	-	% ensquared energy	2,3
Guider	< 0.40	-	-	arc seconds	4
Non-uniformity					
Imaging	< 10	-	30	%, peak	5
Spectroscopy	< 5	-	10	%, peak	6
Guider	< 1	-	2	%, peak	5
Distortion					
Guider	< 1	-	2	%, peak to peak	7
Optical throughput					
Imaging					
Y-band	> 60	55	-	% at 1.00 μm	8
J-band	> 60	55	-	% at 1.25 μm	8
H-band	> 50	55	-	% at 1.6 μm	8
K-band	> 40	40	-	% at 2.2 μm	8
Spectroscopy					
Y-band	> 40	35	-	% at 1.00 μm	8
J-band	> 40	35	-	% at 1.25 μm	8
H-band	> 40	40	-	% at 1.6 μm	8
K-band	> 35	30	-	% at 2.2 μm	8
Guider	> 65	60	-	% at 850 nm	9
Instrument background					
Y-band	< 0.001	-	0.02	e^-/sec/pixel	10
J-band	< 0.001	-	0.02	e^-/sec/pixel	10
H-band	< 0.001	-	0.02	e^-/sec/pixel	10
K-band	< 0.001	-	0.02	e^-/sec/pixel	10
Slit mask light blocking	$> 10^{-7}$	-	-	:1	11
Ghosting					
Imaging	$< 10^{-5}$	-	$< 10^{-4}$	-	12
Spectroscopy	$< 10^{-5}$	-	$< 10^{-4}$	-	12

Notes:

1. Area weighted average rms diameter over the wavelength range of 0.95 to 2.45 μm.
2. Ensquared energy in a 2 x 2 pixel box centered on the image centroid over the wavelength range of 0.95 to 2.45 μm.
3. Achieved in all bands (Y, J, H and K) without refocusing the telescope.
4. Area weighted average rms diameter over the wavelength range of 0.7 to 1.1 μm.
5. This is the peak variation in rms diameter over the full FOV.
6. This is the peak variation in ensquared energy over the full FOV.
7. Total geometric distortion over the entire guider FOV.
8. Instrument throughput, QE of the science detector is not included.

9. Guider optical system throughput, QE of the guider detector is not included.
10. This is the contribution of the instrument background to the total "dark counts"; the goal value is 10% of the goal for science detector dark current.
11. At all wavelengths from 0.95 to 2.45 μm.
12. Intensity of the ghost image compared to the parent image at all wavelengths from 0.95 to 2.45 μm.

7.2.2 Operational Performance Requirements

7.2.2.1 Observing modes

MOSFIRE will provide two observing modes:

- Direct imaging

- Multi-object spectroscopy with a multiplex of up to 46 objects. Slits deployable on a nominal 8" pitch. Minimum slit length 7.3". Adjacent slit bars can be combined to form longer slits in increments of 8". The minimum slit width is 0.5", adjustable in increments of 0.1".

7.2.2.2 Filters

MOSFIRE will provide 10 filters in two six-position filter wheels (5 filters + open in each wheel). Current plans are for MOSFIRE to have 5 standard filters. Specifications for these filters are given in Table 10. Additional filters may be installed prior to delivery depending on requirements identified for specific science programs.

Table 10: MOSFIRE Filters

Filter	**Filter Specifications**						**Description**
(wheel-position)	**CWL (nm)**	**Min. (nm)**	**Max. (nm)**	**Min. T %**	**Goal Passband T %**	**Passband Ripple %**	
1-1	-	-	-	-	-	-	Open
1-2	1048	975	1048	> 80	> 90	< 5	Y Spectrometer
1-3	1250	1150	1250	> 80	> 90	< 5	J Spectrometer
1-4	1640	1460	1640	> 80	> 90	< 5	H Spectrometer
1-5	2170	1930	2170	> 80	> 90	< 5	K Spectrometer
1-6	2150	1990	2150	> 80	> 90	< 5	Ks
2-1	-	-	-	-	-	-	Open
2-2	-	-	-	-	-	-	Spare
2-3	-	-	-	-	-	-	Spare
2-4	-	-	-	-	-	-	Spare
2-5	-	-	-	-	-	-	Spare
2-6	-	-	-	-	-	-	Spare

Note: (Min. = short wavelength half power point, Max. = long wavelength half power point, T = transmission.)

7.2.2.3 Lyot stop

A deployable rotating hexagonal cold Lyot stop matched to the Keck I telescope pupil will be provided. Under control of the MOSFIRE host computer the stop will be deployed or retracted. When deployed the stop will be adjustable in rotation angle to match the hexagonal aperture to the telescope pupil at the current rotator angle. During guiding the stop will track the rotator angle so that the hexagonal aperture of the stop remains matched to the telescope pupil.

7.2.2.4 Spectrometer Grating

The MOSFIRE spectrometer will use a reflection grating that will be interchangeable with a plane mirror for imaging. Two grating angle stop positions will be provided for the reflection grating in order to optimize wavelength coverage across the near-IR wavelength bands.

7.2.2.5 Spectral Coverage

The two grating positions in conjunction with order-sorting filters will maximize the single exposure spectral coverage in each wavelength band for slits located over at least the central 3' of the spectrometer FOV in the spectral dispersion direction.

7.3 Implementation Requirements

7.3.1 Feature Implementation Requirements

7.3.1.1 Dewar Window

The MOSFIRE dewar will have an entrance window approximately 370 mm in diameter. It is essential that condensation or frost does not form on this window. A means must be provided to ensure that this does not occur. The preferred method is heating the window in a manner that does not compromise window transmission over the operating wavelength; increase instrumental background or obstruction the FOV.

Stresses in the dewar window, such as those caused by differences in temperature or pressure, must not produce deformations of the window that affect the optical performance of the instrument.

7.3.1.2 Science Detector Focus Control

In order to permit adjustment of final detector focus during initial testing of MOSFIRE, and also to fine tune the focus for each wavelength range, a mechanism should be provided for a fine focus adjustment of the MOSFIRE science detector. This mechanism should adjust focus by translating the detector along the optical axis with respect to the camera and should be capable of remote operation while the dewar is evacuated and cooled.

7.3.1.3 Guider

The MOSFIRE guider optics will be provided as part of the MOSFIRE optical system and are located on the exterior of the dewar next to the entrance window, providing an offset guider field adjacent to the science FOV. The MOSFIRE guider optics will include a provision for guider focus adjustment.

The MOSFIRE guider camera will be supplied by the observatory and will have an E2V CCD47-20BT detector. The camera will be provided with the required interface for the MOSFIRE guider optics. The camera will also provide motion control electronics to operate the MOSFIRE guider optics focus mechanism. The Observatory guider system software will control the MOSFIRE guider camera.

7.3.2 Common Practice Implementation Requirements

None.

7.3.3 Standards Implementation Requirements

None.

7.3.4 Regulatory Implementation Requirements

None.

7.4 Design Requirements

7.4.1 Technological Design Requirements

7.4.1.1 Optical Component Mountings

All optical components should be mounted so that alignment is maintained during cool down and warm up cycles. Mountings must ensure that excessive stress is not placed on the optical components due to thermal differentials between the optical component and the mount. Mountings must also ensure that alignment of optical components without excessive stress is maintained at all rotator angles and telescope elevations.

Materials used in optical component mountings, particularly elastomers and adhesives must be compatible with the coatings on the associated optical components. All materials used within the dewar must be compatible with vacuum and cryogenic environments, see §8.4.1.1.

7.4.1.2 Alignment Tolerancing

Before assembly all optical components and systems must have a documented optical alignment tolerance budget. During assembly measurements must be made as required to ensure that the stack-up of tolerances does not exceed the tolerance budget.

7.4.2 Regulatory Design Requirements

None

7.4.3 Standards Related Design Requirements

Drawings for optical components should conform to American National Standards Institute (ANSI) / American Society of Mechanical Engineers International (ASME) standard Y14.18M-1986 “Optical Parts (Engineering Drawings and Related Documentation Practices)”.

7.4.4 Integration Related Design Requirements

7.4.4.1 Focal Position

MOSFIRE will be compatible with the *f*/15 Cassegrain focus of the Keck I telescope.

8 MECHANICAL REQUIREMENTS

8.1 Purpose and Objectives

The purpose of this section is to describe requirements for the performance, implementation and design of the MOSFIRE mechanical systems. In many cases these requirements reflect the detailed design of the instrument.

The mechanical requirements address issues of design, reliability and maintainability. Based on experience with previous instruments the observatory is sensitive to certain aspects of performance, implementation and design that have proven to be important factors in the up time of its instruments. The mechanical requirements section has as a main objective the description of the expected performance, features and configuration of the instrument's mechanical systems. A secondary objective is to identify specific areas where experience indicates particular attention is required with respect to performance, implementation or design.

8.2 Performance Requirements

8.2.1 Parametric Performance Requirements

8.2.1.1 General

The general mechanical performance requirements for MOSFIRE are given in Table 11.

Table 11: MOSFIRE Mechanical Performance Requirements

Parameter	***Min.***	***Typ.***	***Max.***	***Units***	***Notes***
Weight	-	-	2300	kg	1
Overall dimensions		-	2030 x 2030 x 3607	mm	2
Temperature					
Operating Ambient	-15	0	20	ºC	
Internal – opto-mechanics					
Operating Temperature	-	120	-	K	
Stability	-0.5	-	0.5		3
Maximum Gradient					
Operating	-	-	< 1	K	
Transient (warm up or cool down)	-	-	3	K	
Internal – science detector					
Operating Temperature	63	70	77	K	4
Stability	-0.1	-	0.1	K	3,5
Cool down time	-	7	10	Days	6
Warm up time	-	7	10	Days	6
Vacuum					
Hold time	12	25	-	Weeks	
Pressure	-	-	1×10^{-6}	Torr	7
Power Dissipation					
To ambient	-	-	50	Watts	
To glycol supply	-	-	1800	Watts	
Glycol cooling					
Temperature rise	-	-	3	ºC	8
Operating pressure	-	80	100	psig	9
Pressure drop	-	-	6	psi	
Flow rate	-	-	9.8	l/min	
Flexure	< 0.1	-	0.3	pixels	10
Alignment					
X, Y and Z axis	-	-	1	mm	11
Rotation about X and Y axis	-	-	0.1	º	11

Notes:

1. Total weight of instrument not including handler.
2. Height, width and length of instrument not including handler. See the Keck I Cassegrain envelope drawing for details.
3. Variation with respect to the nominal operating temperature.

4. The FPA mosaic operating temperature is determined by the QE and dark current requirements (see Table 6.10).
5. Temperature variation must be controlled to ensure adequate zero point stability during exposures.
6. Minimum cool down or warm up time limited by acceptable maximum temperature gradients in internal components during transient conditions.
7. Instrument dewar pressure must be maintained at the level required to maintain the internal temperature.
8. Normal coolant supply temperature is 3 ºC below dome ambient.
9. All cooling system plumbing should be able to withstand a maximum pressure of 100 psig in the event of system pressure regulation failure.
10. Flexure is defined as the magnitude of the shift of the spectral footprint on the science detector during a two hour observation (a single exposure or multiple exposures); this applies to all rotator angles and all telescope elevation angles.
11. Without adjustment of the Keck I Cassegrain telescope mounted portion of the instrument defining points.

8.2.1.2 MOSFIRE Instrument Mechanisms

Mechanisms internal to the MOSFIRE dewar provide for selection of filters, a deployable rotating hexagonal Lyot stop, switching between imaging and spectrograph mode, configuration of the spectrograph multi-object slit mask, flexure correction and a focus adjustment for the science detector. External to the dewar a mechanism is provided for focus adjustment of the MOSFIRE guider optics.

The performance requirements for these mechanisms are given in Table 12. Where three values are given for a parameter they correspond to x, y, and z directions as described in the notes.

All of the requirements in Table 12 apply at the operating temperatures given in Table 6 for mechanisms external to the dewar, and Table 11 for mechanisms internal to the dewar.

The performance of the MOSFIRE Instrument mechanisms is important to obtaining maximum on-sky productivity from the instrument. Mechanism cycle times should be consistent and as short as possible in order to reduce the set-up time for each observation. When multiple axis of motion control are used for reconfigurations it should be possible to simultaneously move all axis of motion that do not otherwise require sequencing because of mechanical design constraints. The mechanisms must operate reliably at all rotator positions and at all telescope elevation angles.

Table 12: MOSFIRE Instrument Mechanism Performance Requirements

Parameter	*Min. (x, y ,z)*	*Typ. (x, y, z)*	*Max. (x, y, z)*	*Units*	*Notes*
Dewar Internal Mechanisms					
Configurable Slit Unit					
Total slits (pairs of slit masking bars)	-	46	-	-	1
Slit position accuracy	-	-	< ±200, ±36, ±250	µm	1
Slit position repeatability	-	-	< ±200, ±36, ±250	µm	1
Slit width error	-	±8.2	< ±25	µm	2
Slit width	360	200	-	µm	3
Slit width resolution	72	-	-	µm	4
Reconfiguration time	-	4.5	<5	min	5
Filter Wheels					
In beam position accuracy	-	0.1	1	º	
In beam position repeatability	-	0.1	1	º	
Cycle time	-	15	30	s	6
Rotating Lyot Stop					
Rotation speed					
Slew	0.8	2	-	º/s	7
Tracking	-	-	0.7	º/s	8
Rotation range	340	-	-	º	
Tracking error	-	0.02	0.5	º	
Position repeatability	-	0.02	0.5	º	
Deploy/retract time	-	<30	45	s	
Grating/Mirror Exchange Turret					
Position accuracy	-	0.21	4	µrad	
In beam position repeatability	-	0.21	4	µrad	
Cycle time	-	45	45	s	6
Flexure Correction					
Adjustment range	-	-	±500	µrad	9
Position accuracy	8	0.5	-	µrad	9
Position repeatability	8	±1	-	µrad	9
Non-linearity	-	-	0.03	%	10
Science Detector Focus					
Adjustment range	-	±275	-	µm	11
Position repeatability	-	±3	-	µm	11
Position resolution	-	0.12	-	µm	11
Non-linearity	-	0.03	1	%	10
Tip/tilt	-	-	30	µrad	9
Guider Focus					
Adjustment range	-	±1	-	mm	12
Position accuracy	15	8	-	µm	
Position repeatability	-	0.6	-	µm	
Position resolution	-	0.3	-	µm	
Focus travel speed	-	-	1	mm/s	
Duty cycle	-	10	-	%	
Lifetime	-	1,000,000	-	cycles	

Notes:

1. The slit mask X-axis corresponds to the spectrometer dispersion direction. The slit mask Y-axis corresponds to the spectrometer spatial or slit bar direction. Z is the conventional optical axis direction.
2. Slit mask X-axis.
3. Corresponds to 0.5" at the telescope focal plane.
4. Corresponds to 0.1" at the telescope focal plane.
5. Worst-case reconfiguration (all slits from one extreme Y position to the other).
6. Cycle time is the time required for full travel from the first position to the last position.
7. The travel time for a full slew of the telescope from horizon to zenith is 72 seconds at a speed of 0.8°/s.
8. Tracking means that the rotator is moving at the variable rate required to compensate for the image rotation produced by the telescope as it follows the sidereal motion of the sky.
9. Tip/tilt about the instrument (Z) optical axis.
10. Non-linearity in closed loop over the full range of travel for each axis.
11. Translation along the camera optical (Z) axis.
12. With respect to the nominal focus position.

Additional detail on the requirements for the CSU may be found in reference 1.

8.2.1.3 Rotator

The rotator is a structure in which the MOSFIRE dewar, cable wrap and electronics racks are mounted and which rotates this assembly about the instrument's optical axis in order to compensate for the image rotation that occurs as the telescope follows the sidereal motion of the sky. The mechanical performance requirements for the rotator are given in Table 13.

Table 13: MOSFIRE Rotator Performance Requirements

Parameter	*Min.*	*Typ.*	*Max.*	*Units*	*Notes*
Rotation speed					
Slew	0.8	2	-	°/s	1
Tracking	-	-	0.7	°/s	2
Rotation Range	-	530	-	°	
Tracking error	-	-	0.5	arc seconds, rms	
Skew	-	-	±0.2	arc seconds, peak	3

Notes:

1. The travel time for a full slew of the telescope from horizon to zenith is 72 seconds at a speed of 0.8°/s.
2. Tracking means that the rotator is moving at the variable rate required to compensate for the image rotation produced by the telescope as it follows the sidereal motion of the sky.
3. Skew is defined as the amount by which the instrument optical axis deviates from telescope optical axis over a full 360º rotation by the rotator.

8.2.1.4 Vacuum Integrity

The MOSFIRE dewar should be capable of maintaining its internal vacuum under continuous cooling for more than 25 weeks without pumping.

8.2.1.5 Power Dissipation

The MOSFIRE instrument must not radiate more than 50 watts of heat into the telescope dome ambient environment. All heat generated by the MOSFIRE instrument in excess of this amount must be carried away by a glycol based cooling system.

8.2.2 Operational Performance Requirements

8.2.2.1 Operating Temperature Range

MOSFIRE should be designed for operation over the ambient temperature range given in §6.2.1.1.3.

8.2.2.2 Configurable Slit Unit

The configurable slit unit (CSU) should meet the performance requirements given in Table 12 at all rotator positions and at all telescope elevation angles. The CSU should meet the performance requirements given in Table 12 at the internal opto-mechanical operating temperature given in Table 11. See reference 1 for additional details on the performance requirements for the CSU.

8.2.2.3 Flexure Correction and Focus Mechanisms

Where piezoelectric actuators are used in these mechanisms they should be operated by a closed loop servo in order to eliminate hysteresis.

8.2.2.4 Vibration

Vibration isolation should be employed as required to isolate sources of vibration within the MOSFIRE Instrument due to moving components such as fans, pumps and motors.

The MOSFIRE Instrument should meet all performance and operating requirements when installed in a vibration environment that conforms to the Generic Vibration Criteria[1] Curve "C" as shown in Figure 3. The MOSFIRE Instrument should not produce vibrations that result in rms velocities in excess of those given in curve "C" of Figure 3.

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[1] Gordon, Colin G. *Generic Criteria for Vibration-Sensitive Equipment*. Proceedings of the SPIE Vol. 1619, pp. 71-85, Vibration Control in Microelectronics, Optics, and Metrology. Gordon, Colin G. editor. SPIE 1992.

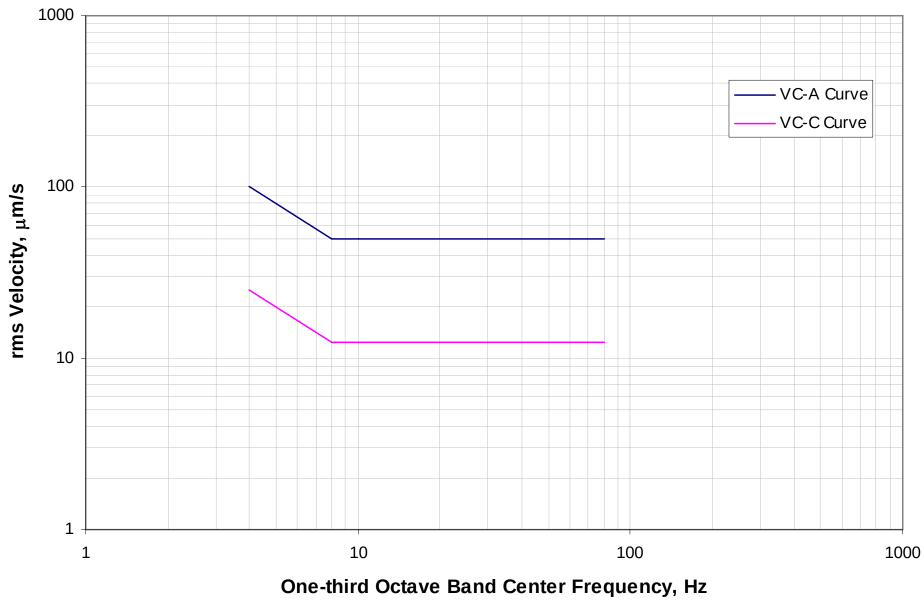

Figure 3: Keck I Telescope Equipment Vibration Limits

8.3 Implementation Requirements

8.3.1 Feature Implementation Requirements

8.3.1.1 MOSFIRE Instrument Dewar

Because the mechanisms internal to the MOSFIRE instrument dewar are difficult to access for service, features should be provided that maximize the reliability of the mechanisms and provide as much information as possible about the status and performance of each mechanism.

All MOSFIRE instrument dewar mechanisms should provide a positive indication that the requested move(s) have been completed. The use of a relative position indicating means in conjunction with limit switches is preferred.

Mechanisms should operate properly with reduced speed over the ambient temperature range given in §6.2.1.1.3. This is essential to permit servicing and verification of proper operation prior to evacuation and cooling of the instrument dewar.

8.3.1.2 Calibration Lamps

MOSFIRE should provide arc-line calibration lamps suitable for daytime use as described in §9.3.1.1. The lamps should be mounted at the front of the instrument with the inside of the instrument dust cover or other suitable deployable reflecting surface used to direct the light into the MOSFIRE optical train.

8.3.1.3 Handler

The handler must incorporate structural components that will maintain its integrity and ensure secure mounting during an earthquake with the MOSFIRE instrument installed as required by seismic standards for a zone 4 earthquake zone (see §8.3.3.1 below).
The handler must incorporate seismic restraint provisions for use when the handler is parked at the storage position.

The handler should be equipped with a removable tractor drive assembly compatible with the existing LRIS tractor drive assembly and drive method.

8.3.1.4 Rotator

A rotator required to rotate the MOSFIRE instrument about the telescope's optical axis in order to compensate for the image rotation that occurs as the telescope follows the sidereal motion of the sky.

The rotator should incorporate a mechanical lockout feature that locks the MOSFIRE instrument in place so that it cannot rotate. This feature will ensure that the instrument will not move due to an imbalance caused by removal of a component for service. Mechanical lockout features should activate an electrical lockout consisting of one or more non-defeatable switches that disable the drive system when the mechanical lockout is active and provide a remote indication that the mechanical lockout is active. The electrical lockout will protect the rotator drive system components as well as prevent unintended drive activation.

The rotator must incorporate a defining point system that is compatible with the defining point system in place at the Keck I Cassegrain position for the LRIS instrument. In particular the components of the defining system on the rotator must incorporate sufficient adjustment range to allow alignment of MOSFIRE with the Cassegrain focal plane without requiring adjustment of the telescope mounted defining system components at the Keck I Cassegrain position.

8.3.1.5 Tractor Drive

A removable tractor drive assembly compatible with the existing LRIS tractor drive assembly and drive method should be provided to move the handler on the Keck I Cassegrain platform and Nasmyth deck rail system.

8.3.1.6 Access and Covers

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 shall 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 instrument to access motors or switches for replacement.

All electronics systems of MOSFIRE (not including the science detector and ASIC inside the instrument dewar) must be accessible for service without returning the instrument to atmospheric pressure.

8.3.1.7 Entrance Window

A remotely operated cover should be provided for the front of the instrument dewar that completely protects the dewar entrance window and guider optics from dust and from damage due to glancing or direct horizontal blows or impacts while in the storage position or moving from storage to the telescope. A typical scenario for the calculation of forces involved is as follows:

> A person moving at a normal walking pace (~1.3 m/s) carrying a 3 meter length of schedule 80 1-1/4" pipe (~14 kg) walks directly towards the front of MOSFIRE. The pipe strikes the cover. The person carrying the pipe does not loose his grip on the pipe and for the purposes of this analysis the Δv in the collision is –1.3 m/s.

The cover should be able to resist the resulting force without damage to the instrument window.

In normal operation it should only be possible for the entrance window cover to open when the instrument is defined at the Keck I Cassegrain position. A key lock operated "local/remote" switch shall be provided to permit local control of the entrance window. When activated this key lock operated switch will defeat all remote control of the entrance window. A second non-defeatable manually activated momentary switch shall be provided to permit temporary remote operation of the entrance window cover when the instrument is not defined at the Keck I Cassegrain position. This switch must be held in the open position to open the window. If the switch is released before the window has reached the open position the window shall close. When this switch is moved to the close position the window shall close without requiring that the switch be held in the close position. If the key lock operated local/remote switch is returned to the remote position the window shall close.

8.3.1.8 Glycol Cooling

All glycol cooling should be plumbed with braided stainless steel hose and stainless steel fittings. Custom manifolds should be used rather than arrangements of "T" fittings and hose. Permanent connections should be made with JIC 37º flare compression fittings or SAE straight thread O-ring fittings. Teflon tape should not be used to seal threaded connections.

Removable connections should be made with ½" Parker Hannifin series FS quick disconnect fittings. The instrument supply coupler is male and the return coupler is 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. should be employed. The Hedland T303 stainless steel models are preferred.

All glycol cooling systems should be provided with a flow switch, Proteus Industries Inc. type 100B110 is preferred, to generate a loss of coolant alarm. This flow switch should interrupt power to the affected system unless a separate over-temperature detection system is provided to remove power from the affected system.

8.3.1.9 Vacuum Systems

Vacuum system implementations must prevent contamination of the dewar from back streaming of oil or other contaminants. Oil free pumps are preferred.

NW 40 size KF flanges are preferred. All vacuum system fittings, including valves and piping and flexible couplings should be stainless steel.

8.3.1.9.1 Pressure Control

Vacuum systems must be equipped with vacuum gauge facilities capable of accurately measuring the pressure in the dewar. This should consist of at least one low vacuum gauge and one high vacuum gauge. A back-up high vacuum gauge is also desired.

Dewars must be equipped with pressure relief valves to protect against over pressure due to the liberation of adsorbed gasses during the warm up process.

8.3.1.9.2 Gettering

Vacuum systems must be equipped with passive gettering for the reduction of water and gasses adsorbed by the dewar walls and internal components.

Where molecular sieves such as Zeolite are used to perform gettering the sieves must be able to be removed and replaced without returning the instrument dewar to atmospheric pressure. Regeneration of the sieves after a warm up must be accomplished in a manner that removes all adsorbed water from the sieve without contaminating the dewar or other components with water. The grain size of molecular sieve material should be selected to minimize the potential for migration of sieve material from the sieve holder. Electropolished stainless steel mesh should be used for the sieve holder. All components of the sieve holder must withstand baking at temperatures up to 350 ˚C without damage, outgassing (except for adsorbed water) or deterioration.

The use of integral getter heaters is discouraged.

8.3.1.10 Cryogenic Systems

Where auto-fill systems are employed for LN_2 cryogen they should be compatible with the auto-fill systems currently in use at the observatory. In the event of auto-fill failure, manual fill must be possible.

Cryogenic systems should provide adequate cryopumping capability to completely condense all residual gasses remaining at initial cool down.

CCR heads should be vibration isolated from the instrument dewar.

Manifolds should be provided for the distribution of helium to the CCR heads according to the capacity of the associated compressors in order to minimize the number of instrument interconnections required.

8.3.2 Common Practices Implementation Requirements

8.3.2.1 Fit and Finish

All steel or iron components should be plated or painted to prevent rust. This includes fasteners and rivets. Welds not ground to the surface or joint profile should be of dress quality. All welds and castings must be stress relieved prior to painting and assembly.

Machined components should be free of tool marks, scratches and material flaws such as inclusions or voids.

Unless otherwise specified all external enclosure and exposed structural elements should be finished in epoxy paint applied in accord with the manufacturer's instructions.

All burrs and sharp edges shall be removed from all fabricated components unless the function of the component requires a sharp edge.

Mild steel surfaces that cannot be painted for functional reasons (such as accurate interface surfaces) shall be protected by a non-tracking anti-corrosion dry film lubricant.

8.3.2.2 Continuity of Shielding and Grounding

Dissimilar metals in contact under conditions where electrolytic corrosion may occur will be isolated by a dielectric finish or insulating spacers. Not withstanding this requirement all components of enclosures that are required to provide protective grounding or EMI shielding must be electrically bonded at multiple points by threaded fasteners, finger stock, or a continuous conductive elastomeric gasket. If grounding straps are used they must be tin plated copper braids not less than 6 mm in width. Anodized aluminum parts must be free of anodizing at the points where electrical contact is required. Painted metal parts must be free of paint at the points where electrical contact is required.

8.3.2.3 Corrosion resistance

All metal components should be finished to prevent corrosion in the operating environment (see Table 6) over a normal 10 year lifetime of operation including handling, maintenance and repair.

All removable fasteners must be plated or treated to prevent corrosion.

Internal components may be plated or paint finished. A contractor who can show conformance to the requirements of MIL-STD-171E "Finishing of Metal and Wood Surfaces" or equivalent should perform any required painting, plating or anodizing.

8.3.2.4 Fasteners

Press fit studs or threaded inserts must be installed in the correct material (i.e. no aluminum inserts in steel) according to the manufacturer's instructions. Samples of such fasteners installed in the actual material should be obtained and subjected to pull out tests prior to use in an actual design. Self tapping screws should not be used for removable covers or to secure components that will have to be removed for repair or replacement.

Fasteners should 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 machine screws should not be used except in special cases where there is no other appropriate design alternative.
Prevailing torque locknuts or lock washers are preferred to thread locking compounds. Soft insert locknuts should have Kel-F or Vespel inserts, and should only be used where subsequent removal is not anticipated.

8.3.2.5 Lubricants

Lubricants must be suited for the low temperature environment encountered at the summit. The base oil in a grease lubricant should have a high viscosity index, a low pour point temperature and a low viscosity at the average operating temperature (based on a 0 ˚C ambient). Greases using synthetic base oils such as Fluoroether or Silicone are preferred.

8.3.2.6 Lubricated Components

Exposed lubricated components such as gear trains or lead screws should be enclosed in a shroud or boot to prevent the collection of dust and dirt and also to prevent accidental contact that may result in the transfer of the lubricant to other surfaces.

8.3.3 Standards Implementation Requirements

8.3.3.1 Structural

The structure of MOSFIRE should meet the zone 4 earthquake survival requirements of Telcordia Standard GR-63-CORE, "NEBS™ Requirements".

8.3.3.2 Vacuum Systems

Vacuum systems should be implemented in conformance with the requirements of ASME HPS-2003, "High Pressure Systems" and NFPA 99C, "Standard on Gas and Vacuum Systems", 2005 edition.

8.3.3.3 Cryogenic Systems

Cryogenic systems should be implemented in conformance with the requirements of NFPA 55, "Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks", 2005 edition.

8.3.4 Regulatory Implementation Requirements

None.

8.4 Design Requirements

8.4.1 Technological Design Requirements

8.4.1.1 Vacuum and Cryogenic Components

Materials used in the construction of components for vacuum environments should have a total mass loss (TML) of ≤ 1%. Materials used in the construction of components for vacuum environments should have a collected volatile condensable materials (CVCM) value of ≤ 0.1%. Values for TML and CVCM should be determined in accord with the methods of ASTM standard E595-93 (2003)e1 "Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment".

Materials for use in vacuum and cryogenic environments must be selected for compatibility with the vacuum and the temperatures to be encountered. Although written primarily for visual wavelength instruments, in particular to protect detector QE in the UV range, guidance in the design and integration of instrument dewars may be obtained from the CARA document "Draft Engineering Guideline for the Design and Integration of Optical Detector Cryostats".

Where LN_2 is used the fill must have an overflow shield so that loss of vacuum does not result from O-ring freezing.

8.4.1.2 Opto-Mechanical Assemblies

Optical and mechanical assemblies, modules or components that must be removed for service shall be provided with locating pins or other features as required to permit repeatable removal and replacement.

Handling features shall be provided on all components unless they are inherently easy to handle without risk of damage. Handles shall be provided (preferably fixed) for components with weights greater than 1 kg up to 25 kg. Heavier components and subassemblies shall be provided with lifting eyes or 'A' brackets.

8.4.1.3 Electrical/Electronic Assemblies and Enclosures

Service access and regulatory compliance in electronic assemblies and enclosures requires attention to the dimensions of components and the space provided for terminal access, wire bending and component mounting.

The mechanical arrangement of the electronic assemblies within enclosures should be designed using techniques that document the proposed arrangement and permit the verification of accessibility, wire bend radii and electrical spacings. Computer aided design techniques including solid modeling may be of value in achieving these objectives.

Where possible electrical and electronic subsystems should consist of rack mounted modules conforming to the 19 inch (482.6 mm) width pattern of Electronic Industries Association (EIA) standard 310-D, "Cabinets, Racks, Panels, and Associated Equipment", section 1. Where rack mounted modules are used each module should be installed using rack slides.

Where rack mounted equipment can be accessed only from the front all rack slides must extend far enough to permit disconnection of any rear panel connections prior to removal of the rack module from the slides.

In systems that consist predominantly of rack mounted modules, all commercial off the shelf (COTS) modules, components and subsystems that are not available in rack mount configurations should be mounted in suitable rack module chassis or on rack mount shelves. All rack module chassis and shelves should be mounted on slides. Components or modules mounted on shelves must be fully enclosed as required to meet all other requirements for grounding, shielding and electrical safety.

Components or modules weighing less than 0.5 kg may be mounted on hinged or screw mounted rack panels provided that all other requirements for grounding, shielding and electrical safety are met.

Rails in 19 inch rack cabinets should be tapped or equipped with captive tapped inserts. Clip nuts should not be used.

Enclosures for electrical and electronic components must provide a continuous shield to prevent the entry or emission of electromagnetic energy. No openings greater than 3 mm in diameter or 3 mm in width and 15 cm in length should be permitted on the exterior of any enclosure for electrical and electronic components. This includes gaps due to access covers, hinges or other enclosure components. Removable covers that do not make continuous contact with the enclosure must be provided with a fastener every 15 cm or with conductive gaskets or finger stock as described in §8.3.2.2.

Thermal analysis should be performed to ensure that all components operate within their temperature limits and to ensure that excess heat is not transmitted to other components or sub-systems of the instrument.

8.4.1.4 Mechanisms

Mechanisms in MOSFIRE should be based on as few identical mechanical assemblies as possible. Mechanisms should be designed in modular assemblies with a minimum of parts and with provisions for simple installation and removal during servicing and repair.

8.4.1.5 Drive Couplings

Shaft couplings for motors, encoders and other drive components should be pinned or locked so that the shaft and coupling cannot slip. Separable couplings should be used whenever possible for motors to facilitate motor replacement.

8.4.1.6 Component Ratings

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

All mechanical moving parts should be selected for a 10 year operating lifetime in the operating environment specified in Table 6.

8.4.2 Regulatory Design Requirements

None.

8.4.3 Standards Related Design Requirements

Enclosures for electrical/electronic components and wiring should conform to the requirements of the Underwriters Laboratories Inc. (UL) Standard for Safety 508 "Industrial Control Equipment". See §9.3.3.1 for references to the relevant requirements.

All electrical and electronic components should be enclosed in a manner that meets the requirements for a NEMA type 4 or better enclosure. The requirements of a NEMA type 4 enclosure are given in the National Electric Manufacturers Association (NEMA) standards publication 250-1997, "Enclosures for Electrical Equipment (1000 Volts Maximum)".

Mechanical drawings should conform to ANSI standard Y14.5M-19994 (R1999) "Dimensioning and Tolerancing" and ASME standard Y14.100-2000 "Engineering Drawing Practices".

8.4.4 Integration Related Design Requirements

8.4.4.1 Mounting Position

MOSFIRE should be designed for installation at the Keck I telescope Cassegrain focal station.

8.4.4.2 Handling

MOSFIRE must be provided with all fixtures and equipment needed to disassemble the instrument dewar for service. If required a crane will be provided by the observatory. The footprint of service fixtures or stands must be minimized because storage and working space on the summit is at a premium.

The profile of all service fixtures or stands must be designed with as low of a center of gravity as possible to resist tipping. Seismic restraints may also be required.

Handling provisions, fixtures and stands must be designed for safe operation and with consideration for ergonomic factors such as range of motion and working posture.

Any temporary clean room or dust cover facilities required for service should be provided with the instrument.

9 ELECTRONIC/ELECTRICAL REQUIREMENTS

9.1 Purpose and Objectives

The purpose of this section is to describe requirements for the performance, implementation and design of the MOSFIRE electronic and electrical systems. In many cases these requirements reflect the detailed design of the instrument.

The electronic/electrical requirements address issues of safety, design, reliability and maintainability. Based on experience with previous instruments the observatory is sensitive to certain aspects of performance, implementation and design that have proven to be important factors in the up time of its instruments. The electronic/electrical requirements section has as a main objective the description of specific requirements for implementation and design.

A key consideration is the safety of personnel and equipment, and proper electrical design and implementation practices in compliance with recognized standards are an essential aspect of electrical safety. A second consideration is the electromagnetic compatibility of the instrument with the observatory systems, and specific implementation and design requirements are given to aid in achieving the required electromagnetic emissions and susceptibility performance.

9.2 Performance Requirements

9.2.1 Parametric Performance Requirements

9.2.1.1 Electrical Power

The electrical power requirements for MOSFIRE are given in Table 14.

Table 14: MOSFIRE Electrical Performance Requirements

Parameter	***Min.***	***Typ.***	***Max.***	***Units***	***Notes***
Instrument Power					
Voltage	108	120	132	Volts AC	1
Current	-	-	20	Amperes	
Frequency	57	60	63	Hz	
Tractor Power					
Voltage	187	208	229	Volts AC	2
Current	-	-	20	Amperes	
Frequency	57	60	63	Hz	
Wire and cable ratings	-30	-	100	°C	

Notes:

1. Power for all instrument electronics and drive motors including the rotator electronics and drive, but excluding the tractor drive for moving the handler.
2. Power for the tractor drive.

9.2.1.2 Science Detector

The science detector will be a Teledyne Scientific and Imaging Hawaii-2RG HgCdTe device with a nominal format of 2048 x 2048 imaging pixels. The requirements for the performance of the science detector are given in Table 15. All measurements are at a temperature of 77 K unless noted otherwise.

Table 15: Science Detector Performance Requirements

Parameter	***Goal***	***Min.***	***Max.***	***Units***	***Notes***
Active Area	2048 x 2048	2040 x 2040	-	X, Y pixels	
Pixel Pitch	-	18	18	μm	
Fill Factor	> 98	> 95	-	%	
Outputs	-	32	-		
Dark Current	< 0.01	-	< 0.05	e^-/pixel/s	2
Dark Current Shift	< 0.001	-	< 0.005	e^-/pixel/s	3
Dark Current Decay Time	< 4	-		s	4
Multiplexer Glow	< 0.01	-	< 0.05	e^-/pixel/read	5
Charge Storage Capacity	≥ 100,000	-	-	e^-/pixel	6
Persistence	<0.2			%	7
Quantum Efficiency					
Y-band (0.97 to 1.1 μm)	≥ 80	60	-	%	8
J-band (1.10 to 1.40 μm)	≥ 80	60	-	%	8
H-band (1.46 to 1.8 μm)	≥ 80	65	-	%	8
K-band (1.9 to 2.45 μm)	≥ 80	65	-	%	8
Cut-on Wavelength	0.9	-	-	μm	9
Cut-off Wavelength	2.50	-	2.55	μm	10
Operability	≥ 99.5	98	-	%	11
Pixel Readout Rate	-	0.1	5	MHz	12
Operating Temperature	77	65	80	K	13
Power Dissipation	5	-	20	mW	14
Flatness	≤ 10	-	20	μm	15

Notes:

1. Not used.
2. Array mean including any continuous multiplexer glow during readout or integration, the state of the multiplexer must be defined.
3. Change in the measured dark current after readout for pixels exposed to 90% or more of the maximum detector charge storage capacity.
4. Time required for dark current to return to ~90% of the long-term soak value (lowest observed dark current) after any part of the detector active area is exposed to flux below the saturation (maximum charge storage capacity) level.
5. Maximum value must not cause read noise maximum to be exceeded when using multiple sampling schemes. This statement also applies to charge injected from non-photon sources.
6. At manufacturer's specified nominal reverse bias voltage.
7. Measured using CDS readout and referenced to the saturation level of each pixel. Persistence is defined as the amount of charge detected in each pixel of a black frame readout immediately following a readout and reset where that pixel was exposed to the saturation level.

8. Low QE levels in any of these wavelength bands (< 70%) are not acceptable.
9. The wavelength cut-on is the wavelength at the short wavelength end of the spectral response where the detector QE drops to 50% of the mean value in the Y-band.
10. The wavelength cut-off is the wavelength at the long wavelength end of the spectral response where the detector QE drops to 50% of the mean value in the K-band.
11. Operability refers to the number of pixels with a QE > 30% of the mean value over the wavelength range of 0.9 µm to 2.5 µm and which also have dark current $\leq$ 0.05 e^-/pixel/s
12. Continuously variable.
13. Exact operating temperature may be adjusted to obtain best performance.
14. At a 100 KHz readout rate.
15. Peak to valley over the detector active area, a ±10 µm focus error changes rms image diameters by ~2 µm.

It is recognized that high pixel count HgCdTe detectors will not have 100% functional pixels. However, given the desire for a high level of imaging performance and the potential for uniformity problems due to operability limits, the location and number of dead pixels should be given special attention in the specifications for the detectors.

Since the final sensitivity of the instrument is dependent upon both optical throughput and detector quantum efficiency (QE), the expected values for instrument sensitivity will need to be reconciled with the instrument optical throughput and the actual QE of the science detectors. A set of acceptance/selection criteria for the detectors will be required that relate sensor QE to the required instrument sensitivity.

9.2.1.3 Science Detector and Readout ASIC or Controller

As a system the performance of the science detector and readout ASIC or detector controller will be as shown in Table 16.

Table 16: Science Detector and Readout ASIC or Controller Performance Requirements

Parameter	*Goal*	*Min.*	*Max.*	*Units*	*Notes*
Readout Channels	-	32	-		
Bit Depth	-	16	-	bits/pixel	
Read Noise	≤ 15	-	20	e^-	1
Crosstalk	50,000:1	10,000:1	-	ratio	2
Readout Time	-	-	< 2	S	3
Uniformity	≤ 5	< 10	-	%	4
Non-linearity	< 1	-	< 2	%	5
Zero Point Variation	< 1	-	3	e^-	6
Pixel Readout Rate	-	0.1	5	MHz	7
Operating Temperature					
ASIC and Carrier Board	-	35	80	K	
Jade 2	-	263	303	K	
Power Dissipation					
ASIC and Carrier Board	< 100	-	200	mW	8
Jade 2	200	-	500	mW	9
Jade 2 Power Input					
Voltage	-	4.75	5.25	Vdc	
Current	-	-	0.1	A	9
Ripple	-	-	0.1	%	10

Notes:

1. Single CDS read at a pixel readout rate of 200 KHz. It is assumed that with multiple sampling (16 reads) noise of ~5 e^- rms.
2. Between any 2 detector readout channels, method of measurement to be specified.
3. Readout time as required to avoid detector saturation, all readout ports in use.
4. Total uniformity of the detector response at any instrument wavelength and over the full useful dynamic range before flat fielding and other response corrections.
5. Residual non-linearity, after correction, of the system incident flux to digitizer count transfer function over the full range from dark to saturation.
6. Amount of variation in the unexposed portion of a series of short dark frame exposures taken at the operating temperature with the detector temperature controller in operation and maintaining the detector temperature to ±0.1 K. CDS readout mode assumed.
7. Continuously variable.
8. Under all conditions including the nominal 100 kHz readout rate.
9. At a nominal Jade2 power input voltage of 5.0 Vdc.
10. Peak to peak ripple as a percentage of input voltage.

9.2.1.4 Power Dissipation

See §8.2.1.5.

9.2.1.5 Compatibility

MOSFIRE must be electrically compatible with the telescope environment.

9.2.1.6 Temperature and Humidity

All electronics in MOSFIRE should be designed for operation in an ambient temperature range of –10 °C to 30 °C and a relative humidity of 95%, non-condensing.

9.2.1.7 Cable and Wire Ratings

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

9.2.2 Operational Performance Requirements

None.

9.3 Implementation Requirements

9.3.1 Feature Implementation Requirements

9.3.1.1 Calibration Lamps

MOSFIRE should provide arc-line calibration lamps suitable for daytime use. These lamps should be remotely controllable and provide sufficient lines for calibration of spectra in each of the four MOSFIRE operating wavelength bands. Sufficient flux of adequate uniformity shall be provided so that reasonable exposure times consistent with pre-observing afternoon calibrations (~1 hour total duration) may be obtained.

9.3.1.2 Emergency Stop Input

The MOSFIRE instrument should be provided with an emergency stop input that stops all instrument motion (including the rotator) and closes the entrance window cover when the observatory emergency stop signal is activated.

9.3.1.3 Rotator

The rotator should be equipped with a local control switch to defeat remote control during service and maintenance operations. The rotator module should be equipped with a motion stop switch to prevent motion of the mechanism during emergencies, service and maintenance.

9.3.1.4 Host Computer

WMKO has standardized on computers running the Sun Solaris operating system as the primary platform for instrument host computers. The host computer for MOSFIRE will be a Sun Fire V245 or similar server.

This computer should be provided with a dedicated disk array for data storage. Connections to the observatory wide “public” network and the instrument private network should be made two separate network interfaces in the host computer. This will isolate the time critical instrument control and data communications from the Observatory wide network traffic. The host computer must be configured to ensure that there are no routes or bridges between the Observatory wide network and the instrument private network.

9.3.1.5 Data Storage

A local, dedicated disk array should be provided for storage of MOSFIRE science data. This disk drive should be interfaced to the host computer using a high performance data transfer protocol. The disk array should utilize a RAID 3 or 5 configurations to permit replacement of a failed disk without loss of data. The capacity of the disk array should be sufficient to contain data from at least 14 typical observing nights.

The disk array should use disk drives approved and tested by WMKO for operation at the summit altitude. The disk array should use front accessible, hot pluggable disk drive modules in an EIA 19 inch rack insert.

9.3.1.6 Target and “Embedded” Computers

If a target computer is a PC type computer located on or integral to the MOSFIRE instrument, it should be an industrial/server grade 1U, 19” EIA rack mount computer equipped with a flash disk as the system disk and running a WMKO approved operating system. The computer should be equipped with local monitor, mouse and keyboard connections for test and diagnostic purposes.

If a CD-ROM drive is required it should be a removable external drive that is connected when required for maintenance.

If a remote computer is used for a target computer the computer should be a Sun workstation or server running a WMKO approved version of the Solaris operating system.

9.3.1.7 Instrument Connection Panel

All interconnections to the MOSFIRE instrument should be made at a single location on the stationary portion of the rotator frame. This location should be provided with one or more instrument connection panels where all electronic and electrical connections are made. This panel should also incorporate circuit breakers and other protective devices as required to protect the wiring of the MOSFIRE instrument dewar and the rotator. Additional panel(s) for glycol and CCR helium connections should also provided at the same location.

9.3.1.8 Printed Circuit Boards

All removable plug-in printed circuit boards should be equipped with positive retention features. Extractors should be provided for all circuit boards where high insertion and withdrawal forces are expected.

9.3.2 Common Practices Implementation Requirements

9.3.2.1 Stray Light

The MOSFIRE instrument should not produce stray light from LED or lamp indicators, optical switches or optical shaft encoders.

LED or lamp indicators should not be used on the exterior of the MOSFIRE instrument. Any indicators required for service should be concealed behind a cover or access door. Optical switches or shaft encoders must be optically baffled or enclosed so that no stray visible or infrared light is emitted into the telescope optical path or dome environment.

All exterior parts of the MOSFIRE instrument should be examined for stray light emissions with a night vision device with a light gain of at least 50,000[2]. A person known to have normal photopic and scotopic visual sensitivity should conduct the examination under dark adapted conditions.

9.3.2.2 Digital Control and Status Communications

Where ever possible digital communications for control and status information between subsystems and modules should be implemented using the TCP/IP protocol over a 100Base-TX Ethernet interface. Purpose built or custom designed electronic modules and circuits that require such communication should be designed with these protocols.

[2] This is a typical specification for generation III night vision monoculars such as the ITT 160 Night Mariner.

Where legacy or COTS hardware is used and only serial communications is available, RS-232 signal levels with an asynchronous 8 bit format may be used. RS-232 data rates should be the maximum practical for the required cable length, and RS-485 levels with electrical isolation (to prevent common mode problems and ground loops) should be used for cable runs longer than 3 meters.

All RS-232 controlled devices should be interfaced to the instrument computers using a terminal server. The Lantronix ETS8PS is the preferred terminal server at WMKO.

9.3.3 Standards Implementation Requirements

9.3.3.1 Electrical Safety

The design and construction of MOSFIRE should conform to the requirements of UL Standard for Safety 508 "Industrial Control Equipment". The relevant portions of UL 508 may be summarized as follows:

1. Specific metal gauge requirements are given in tables 6.1 (page 22) and 6.2 (page 23).
2. Specific details for doors and covers are given in section 6.4 (pages 24 through 27).
3. Specific requirements for the design of ventilation openings are given in section 6.9 (pages 31 through 33).
4. Specific details for controlling the accessibility of live parts are given in section 6.17 (pages 36 through 37 and figures on pages 38 and 39).
5. Requirements for insulating material that directly supports live parts are given in section 15 (pages 42B through 43). This includes printed circuit boards.
6. Specific requirements for the protection of control circuits are given in section 18.2 (pages 47 through 48B).
7. Specific requirements for internal wiring are given in section 21 (pages 50 through 56A).
8. Section 34 (page 68) gives specific requirements for the separation of circuits.
9. Section 35 (page 68A) gives specific requirements for optical isolators.
10. Specific details for required electrical spacings are given in section 36 (pages 68A through 73).
11. Specific details for grounding are given in section 40 (pages 79 through 82).
12. Table 43.1 (pages 84C through 84E and explanations on pages 84E and 84F) indicates the maximum permissible temperature rises for specific materials and components.
13. Table 43.2 (page 86) indicates the ampacity of various insulated conductors.
14. Section 49 (pages 99 through 100A) gives the requirements for dielectric voltage-withstand testing.
15. Section 62 (pages 128B and 128C) gives specific requirements for device ratings.
16. Section 63 (pages 128E through 133) gives specific requirements for markings. These are summarized in table 67.1 (pages 134A through 136B).

17. Additional requirements for programmable controllers are given in sections 177 through 193 (pages 196B through 201)

The design and construction of the wiring of MOSFIRE should 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 MOSFIRE will be installed or operated. The requirements given in §9.2.4 are consistent with the applicable portions of the National Electric Code.

9.3.3.2 Electromagnetic Compatibility

Standards exist that specify the test conditions and limits for electromagnetic emissions and electromagnetic immunity. They do not give information on how to achieve compliance. In the absence of such information CARA believes that a satisfactory level of electromagnetic emission and immunity compliance can be achieved by following the requirements given in sections 8.3.2.2, 8.4.1.3 and 9.3.4.5 of this document.

For information on the permitted level of emissions and the required level of immunity the following standards may be consulted:

1. The conducted and radiated emissions limits for unintentional radiators are specified in Title 47 CFR Part 15, sections 15.107 and 15.109 for class B devices.

2. Electromagnetic immunity requirements are given in the Council of the European Communities Directive EMC 89/336/EEC, and the reference standard of the European Committee for Electrotechnical Standardization (CENELEC) EN 50082-1:1997 "Electromagnetic compatibility-Generic immunity standard-Part 1: Residential, commercial and light industry" published in the Official Journal of the European Community on March 1, 1998.

9.3.4 Regulatory Implementation Requirements

9.3.4.1 AC Line Connections

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.

9.3.4.2 Covers

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

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

9.3.4.3 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.

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.

Phase, neutral and ground conductors shall be sized using table 43.2 of UL 508.

9.3.4.4 Overcurrent Protection

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.

9.3.4.5 Grounding and Shielding

The enclosures of ac line connected components shall be grounded in conformance with the requirements of the National Electric Code and any local codes. 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.

All components capable of generating electromagnetic emissions in excess of the limits established in the standards referenced in 9.3.3.2 above will be shielded and the shielding grounded to limit electromagnetic emissions to the levels allowed by the standards referenced in 9.3.3.2. All components susceptible to externally generated electromagnetic emissions in excess of the limits established in the standards referenced in 9.3.3.2 above will 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 9.3.3.2.

9.3.4.6 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.

9.3.4.7 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.

9.4 Design Requirements

9.4.1 Technological Design Requirements

9.4.1.1 Motion Control Systems

The preferred motion controllers for stepper and servomotors are Galil or Pacific Scientific programmable motion controllers. The preferred motion controller for piezo devices (tip/tilt and focus) is the 500 series from Physik Instrumente.

9.4.1.2 Power Ratings

All power dissipating components to be cooled by free air convection must be derated to 80% of their sea level absolute maximum average power dissipation ratings.

9.4.1.3 Wiring and Interconnections

9.4.1.3.1 Connector and Cable Mounting

Cable and wiring strain relieves should be designed so that strain relief and wiring integrity is not compromised by opening access doors or removing service access covers.

Connectors should not be mounted on service access covers or on access doors.

9.4.1.3.2 Cable and Wire Routing

Cables and wiring must be routed so that they do not interfere with the optical path of the instrument. 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 should be provided when necessary, but all cables should be routed neatly and secured at regular intervals with wire ties or lacing cord.

9.4.1.3.3 Labeling of Interconnections

All external, interconnecting cables and any corresponding panel mounted connectors must be uniquely identified and labeled. The labeling and identification should be in a clearly visible and non-removable form. This identification scheme must be identical to that used in the system documentation. Identification of cables by color-coding is not a substitute for clear labeling.

9.4.1.3.4 Interconnections

External interconnections of low voltage ac and dc circuits should be shielded whenever there is a reasonable possibility that those interconnections will be subject to electromagnetic interference or unwanted coupling.

Cable shields should 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 should 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 should be electrically continuous with the connector housing, and WMKO prefers 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 should be discussed with WMKO.

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) <u>before</u> all other connections during connector insertion and break circuit common connections (dc reference or ac protective ground) <u>after</u> all other connections during connector removal.

9.4.1.3.5 Data Communications

9.4.1.3.5.1 Control and Status Communications

Where ever possible digital communications for control and status information between subsystems and modules shall be implemented using the TCP/IP protocol over a 100Base-TX

Ethernet interface. Purpose built or custom designed electronic modules and circuits that require such communication shall be designed with these protocols.

Where legacy or COTS hardware is used and only serial communications is available, RS-232 signal levels with an asynchronous 8-bit format may be used. RS-232 data rates shall be the maximum practical for the required cable length, and RS-485 levels with electrical isolation (to prevent common mode problems and ground loops) shall be used for cable runs longer than 3 meters.

Control, science data and guider image data communications between the MOSFIRE (instrument control electronics, detector controllers and rotator) and remotely located computers should be via a multi-strand fiber optic bundle. Fiber optic bundle connections should be via panel mounted connectors equivalent in performance to connectors that conform to military specification MIL-C-38999 series IV.

9.4.1.3.5.2 Science and Guider Image Data

Science data and guider image data communications may be via proprietary protocols such as those employed with the SDSU-III detector controllers or they may be via high bandwidth industry standard protocols such as Fibre Channel, 1000Base-SX or 100Base-TX.

9.4.1.3.5.3 Network Communications

Control communications between MOSFIRE instrument and the MOSFIRE target and/or host computers should employ the TCP/IP protocol over a private 100Base-TX network (the MOSFIRE private network) conforming to the Institute of Electrical and Electronics Engineers (IEEE) Standard 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)”. Cabling and terminations should conform to Telecommunications Industry Association and Electronics Industry Alliance (TIA/EIA) standard TIA/EIA-568-B “Commercial Building Telecommunications Cabling Standards”.

The MOSFIRE private network may have a number of devices. Network devices that are physically part of the instrument should be routed to the remotely located devices in the Keck I computer room (host or target computers) via 100Base-TX switches located on the MOSFIRE instrument and in the MOSFIRE computer rack. The switches should be interconnected by a 1000Base-SX fiber optic link.

9.4.2 Regulatory Design Requirements

See §9.3.4.

9.4.3 Standards Related Design Requirements

Connectors used for low voltage ac and dc circuits should be types equivalent in performance to connectors that conform to military specification MIL-C-38999 series IV.

9.4.4 Integration Related Design Requirements

9.4.4.1 Rotator

The rotator drive system should be designed to be compatible with the Keck I Cassegrain auxiliary servo amplifier. The pinout and connector type for the interconnection of the rotator to the Keck I Cassegrain panel must be compatible with the existing Keck I Cassegrain panel pinout and connector.

10 SAFETY REQUIREMENTS

10.1 Purpose and Objectives

Safety is the paramount concern for all activities at the observatory. Specific regulations apply to health and safety as described in §6.3.3, §9.3.3 and §9.3.4. The purpose of this section is to provide requirements related to specific safety concerns during the operation and handling of MOSFIRE.

10.2 Scope

Unless otherwise indicated all of the requirements of this section apply to all components of MOSFIRE.

10.3 Performance Requirements

10.3.1 Parametric Performance Requirements

None.

10.3.2 Operational Performance Requirements

The normal operation of MOSFIRE 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.

As part of the processes for the detailed design review and the pre-shipment review the safety of the system will be reviewed. In general it is expected that conformance to the requirements of this document and the referenced regulatory standards will ensure a safe system.

10.4 Implementation Requirements

10.4.1 Feature Implementation Requirements

10.4.1.1 Local Control

Mechanisms internal to the MOSFIRE instrument dewar will not be accessible during normal operation. However, during servicing a means must be provided to ensure that all MOSFIRE mechanisms are under local control and remote control is locked out.

The rotator should be equipped with a local control switch to defeat remote control during service and maintenance operations. The rotator should be equipped with a motion stop switch to prevent motion of the mechanism during emergencies, service and maintenance. The rotator should also be connected to the Keck I telescope emergency stop circuit to disable rotator motion when the emergency stop is activated.

10.4.1.2 Mechanical

All areas of the rotator where exposed moving parts can create a pinch hazard should be clearly marked with a hazard warning label or equipped with shrouds to prevent accidental contact.

The rotator should incorporate a mechanical lockout feature that locks the MOSFIRE instrument in place so that it cannot rotate. This feature will ensure that the instrument will not move due to an imbalance caused by removal of a component for service. Mechanical lockout features should activate an electrical lockout consisting of one or more non-defeatable switches that disable the drive system when the mechanical lockout is active and provide a remote indication that the mechanical lockout is active. The electrical lockout will protect the rotator drive system components as well as prevent unintended drive activation.

10.4.1.3 Entrance Window Cover

The instrument dewar entrance window should be equipped with a remotely operated cover that should be interlocked to the instrument and telescope interlocks so that the window cover is prevented from opening except when the instrument is defined at the Keck I Cassegrain operating position. Special provisions for local operation of the entrance window cover while the instrument is in other positions may be required, but remote operation of the entrance window cover should only be possible when the instrument is defined at the Keck I Cassegrain position.

The window cover must incorporate safety sensor switches to prevent injury to personnel as it closes.

The window cover must be designed to protect the window from damage as described in §8.3.1.7.

10.4.1.4 Electrical

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.

See §9.3.3.1 for additional electrical safety requirements.

10.4.2 Common Practice Implementation Requirements

None.

10.4.3 Standards Implementation Requirements

None.

10.4.4 Regulatory Implementation Requirements

See §6.3.3, §9.3.3 and §9.3.4.

10.5 Design Requirements

10.5.1 Technological Design Requirements

10.5.1.1 MOSFIRE Instrument Dewar

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

If closed loop or servo systems are used in the MOSFIRE motion control systems these servo loops should 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 should 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 should be closed when not actuated (N.C. contacts). Motion control software should be designed so that a disconnected limit switch will appear to be active, inhibiting further motion towards that limit. Motion control software should 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 should 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.

10.5.1.2 Rotator

No part of the rotator should move when ac mains power is applied to or removed from the rotator. The rotator motion control hardware should inhibit all motion during a power on/reset.

The rotator motion control system should 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 should 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 should be closed when not actuated (N.C. contacts). Motion control software should be designed so that a disconnected limit switch will appear to be active, inhibiting further motion towards that limit. Motion control software should 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.

Position encoders should 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.

10.5.2 Regulatory Design Requirements

As indicated in the sections for overall, mechanical and electrical requirements the design of MOSFIRE must conform to all applicable regulatory requirements.

10.5.3 Standards Related Design Requirements

None.

10.5.4 Integration Related Design Requirements

None.

11 SOFTWARE REQUIREMENTS

11.1 Purpose and Objectives

The software requirements section describes requirements for performance, implementation and design. Based on experience with previous instruments the observatory is sensitive to certain aspects of performance, implementation and design that have proven to be important factors in the up time of its instruments. The software requirements section has as a main objective ensuring compatibility of the MOSFIRE software with existing observatory software systems. A secondary objective is guiding the selection of software architecture and implementation decisions towards those that fit within the software skill sets at the observatory in order to maximize the ability of the observatory to support and maintain the MOSFIRE software.

WMKO has established a number of standards for software and these standards form an integral part of the software requirements for MOSFIRE.

Specific requirements are given in areas where repeated problems have affected the availability of instruments. Among these are issues of network reliability, reliability of fiber optic data connections to detector controllers, and problems with handling errors in a manner that minimizes the loss of observing time by providing useful error messages and avoids total system resets or power cycling to restore proper operation.

11.2 Scope

Unless otherwise indicated all of the requirements of this section apply to all software components of MOSFIRE.

11.3 Performance Requirements

11.3.1 Parametric Performance Requirements

11.3.1.1 Reliability

All software components of MOSFIRE should be tested under simulated operating conditions and should achieve at least 150 hours of continuous operation without a fault. The reliability of the following software components should be tested and confirmed:

a. Host OS
b. Target computer(s) OS
c. Host application
d. Target application(s)
e. Detector controller code

11.3.1.2 Fiber Optic Data Links

Fiber optic data links should tolerate up to 10 db of attenuation due to interconnection losses without impairment of performance or reliability.

11.3.1.3 Data Transfer Performance

Data transfer from the MOSFIRE host computer to the disk storage should be at a rate sufficient to keep up with the time to readout and co-add of the minimum useful number of frames taken at the shortest practical exposure time.

11.3.1.4 Display Updates

A display facility for science detector readouts should be provided and this display should update as quickly as possible at the completion of each exposure.

11.3.2 Operational Performance Requirements

11.3.2.1 Overhead

Software should permit simultaneous motion of multiple mechanisms in order to minimize the time required to complete each instrument set-up between observations. When multiple axis of motion control are used for reconfigurations it should be possible to simultaneously move all axis of motion that do not otherwise require sequencing because of mechanical design constraints.

11.3.2.2 Error Recovery

11.3.2.2.1 Loss of Network Connections

All MOSFIRE software should gracefully recover from the interruption of TCP/IP network connections, fiber optic connections or USB connections any time. This disconnection may occur due to physical interruption of the network connection, or the power cycling or hardware reset/reboot of the device at the other end of the network connection. Software should implement reasonable timeouts and handle all TCP/IP network errors so that recovery from a network fault is as automatic as possible. Specifically, the components that have not experienced power cycling or a hardware reset/reboot must recover from the loss of the network connection without requiring that they be reset or rebooted.

Whenever possible it is expected that the system will perform in a manner that permits recovery from any of the following conditions without requiring manual resetting of any hardware component and where practical without loss of data (except in the case of the link from detector controller to target where data loss is inevitable and even a pause in the detector readout will typically produce artifacts in the image):

1. Loss of network or data connections:
   a. Host to target(s)
   b. Host to public network
   c. Target(s) to detector controller(s)
2. Power cycling:
   a. Host
   b. Target(s)
   c. Detector controller(s)
3. Hardware resets:
   a. Host
   b. Target(s)
   c. Detector controller(s)

When recovery is not possible, and for the cases where the host computer is not the system being reset or power cycled, it is expected that the user interface software in the system will provide a useful diagnostic message or warning to the operator without crashing or locking up.

11.3.2.2.2 Detector Controller Aborts

The science detector controller should support aborts at any time during an exposure or during any readout of greater than 5 seconds duration. When an exposure is aborted it should be possible to readout and save the exposure data.

11.3.2.2.3 Data Disk Full

The software will implement some version of certain well known mechanisms for avoiding this (roll-over using DISKLIST when the directory pointed to by OUTDIR is full and so on). It is understood that there is no requirement to cope with failed NFS cross mounts.

11.3.2.3 Execution Speed and Command Latency

The response time requirements for the MOSFIRE software are given in Table 17.

Table 17: Software Latencies

Software Function	*Goal*	*Min.*	*Max.*	*Units*	*Notes*
Status requests	0.1	-	0.2	s	
Motion commands	0.1	-	0.2	s	
Observatory E-stop	0.01	-	0.05	s	
Detector controller commands	0.1	-	0.2	s	1
Detector controller aborts	> 1	-	5	s	2
Application software startup and initialization	> 10	-	30	s	3

Notes:

1. Not including the exposure or readout times.
2. Not including the time elapsed prior to the abort command for the exposure in progress or the readout in progress.
3. Not including the actual time required to perform the operating system re-boot and associated initializations.

11.4 Implementation Requirements

11.4.1 Feature Implementation Requirements

11.4.1.1 User interfaces

Graphical user interfaces (GUIs) should be provided for all observing control functions. These interfaces must be implemented in a manner consistent with other WMKO instruments and in conformance with KSD 210. User interfaces based on the OSIRIS heritage are preferred.

If the MOSFIRE user interfaces are written in Java then they should communicate with the MOSFIRE servers using the OSIRIS KTL to Java interface, KJava. Table 18 lists the user interfaces that should be provided.

Table 18: MOSFIRE Graphical User Interfaces

Name	Description
MOSFIRE Exposure Control GUI	Sets up exposures (integration time, coadds, etc.) and starts and aborts them
MOSFIRE Exposure Status GUI	Tracks the progress of an exposure, showing parameters of the current exposure and the remaining integration time
MOSFIRE Mechanism Control GUI	Controls the mechanisms of the instrument, only filter and observing mode (imaging or spectroscopy) parameters are provided, and the filter, pupil wheel, grating turret and focus mechanisms are moved according to those two parameters
MOSFIRE Mechanism Status GUI	Shows the status of each MOSFIRE mechanism, except the CSU
MOSFIRE CSU Control GUI	Provides controls to configure the CSU
MOSFIRE CSU Status GUI	Shows current position of bars in CSU
MOSFIRE Temperature Control GUI	Provides controls to set the MOSFIRE science detector operating temperature
MOSFIRE Temperature Status GUI	Shows current temperatures at various locations in the instrument
MOSFIRE Pressure Status GUI	Shows the current dewar pressure
MOSFIRE Power Control GUI	Provides controls to turn on and off power to selected components
MOSFIRE Power Status GUI	Displays the power status of selected components
MOSFIRE Telescope GUI	Provides an interface to the telescope drive and control system, such as offsetting and control of the instrument rotator
MOSFIRE Calibration GUI	Provides controls for the calibration lamps and dust cover

Operation of the MOSFIRE guider (including focus) will be performed using the Observatory's MAGIQ acquisition and guiding system software.

11.4.1.2 Image Display

The image display facility should be DS-9 or the Quicklook II software developed for OSIRIS (with a 2D mode for spectral data).

11.4.1.3 CSU Configuration

A CSU configuration program is required. This software should be modeled on the best practices from the processes currently in use at WMKO to design slit masks for the LRIS and DEIMOS instruments. The configuration software should also include a feature similar to the DEIMOS DSIMULATOR application for previewing slit mask configurations.

The MSCGUI should also support the generation of slit configurations during observing, although for reasons of efficiency this practice will not be encouraged except for special circumstances such as transient object follow up.

Slit mask alignment software should also be provided based on the LRIS "xbox" alignment software and procedures.

11.4.1.4 Data Reduction Pipeline

A data reduction pipeline (DRP) should be provided for use with MOSFIRE science data.

While there are important differences in near-IR observing protocols (e.g.: dithering; beam-switching) to cope with OH (and detector) variability that have to be taken into account, the DRP developed for the DEIMOS instrument at WMKO offers a starting point for the development of a MOSFIRE DRP. Accordingly it is expected that the DRP for MOSFIRE will be developed from the DEIMOS DRP.

11.4.1.5 MOSFIRE Target Computers

All MOSFIRE target computer(s) should be configured to auto-boot their operating systems and auto-execute their target application software and at power on/reset.

11.4.1.6 Software Licenses

Any licensed software required for operation of the MOSFIRE software must be supplied with an adequate number of fully paid licenses to permit operation of all MOSFIRE software. Software using IDL or other licensed development packages should be designed to operate using a virtual machine or other software package that is free of royalty or license fee costs. Where this is not possible node locked licenses will be required for each host or target computer (where applicable).

11.4.2 Common Practice Implementation Requirements

MOSFIRE host and target software should be written in C/C++ to run under a WMKO approved operating system. All communications between the instrument software components and the user interfaces and the telescope systems will be based on keywords conforming to WMKO standards.

Where Java is used to develop user interfaces the implementations should be consistent with the OSIRIS implementations. Java user interfaces must run under the current versions of the Solaris operating systems and Solaris window managers in use at WMKO.

11.4.3 Standards Implementation Requirements

MOSFIRE software should conform to the requirements of KSD 201 and KSD 210. All communications between the MOSFIRE target software and the MOSFIRE host software should be via keywords conforming to the requirements of the Keck Task Library (KSD 8).

11.4.4 Regulatory Implementation Requirements

None.

11.5 Design Requirements

11.5.1 Technological Design Requirements

11.5.1.1 Client-Server Architecture

The basic architecture of the MOSFIRE software should be based on client-server architecture. The server components of the system should provide keyword services compliant with the Keck Keyword Interface standards.

11.5.1.2 Communications Protocols

Client-server communications should be via TCP/IP using a WMKO approved protocol. It is not required that existing message formats or services be used, provided that they are capable of supporting the Keck Task Library (KTL) as described in KSD 8.

Standard implementations of RS-232 serial communications may be used for communication with COTS hardware that does not support TCP/IP network communications.

11.5.1.3 Keywords

Keywords should be defined in collaboration with WMKO software staff. The action of keywords or acceptable ranges of values should not be dependent on previous values of the keyword. Keywords should conform to the formats described in KSD 8 and 28.

11.5.1.4 Target Software

Target software is by definition software that provides direct low level control of electronic or electromechanical systems through direct hardware interfaces. Target software may run on so-called “embedded” computers that are part of the instrument’s electronics hardware, or target software may run on a remote computer connected via data communications interfaces to hardware that has its own embedded computer that runs its own control software and does not directly execute the target software. See §9.3.1.4 for operating system and computer hardware requirements.

In general target software will implement a keyword service to allow control of the instrument’s electronic or electromechanical systems. In some cases, such as the rotator target software, the target software may also implement client functionality, for example when monitoring DCS commands to determine rotator position. Communications with the host software should be via TCP/IP and the Keck Keyword Interface.

11.5.1.5 Host Software

MOSFIRE host software should provide the user interfaces for instrument control and image display. All host software functions should be accomplished using keywords conforming the to the Keck Keyword Interface standards.

Keyword level access shall be provided for all mechanism control and other adjustments including "engineering level" adjustments such as detector focus and operating temperature set point.

11.5.1.6 Science Data File Formats

Header data for the science data files will incorporate keywords that fully describe the conditions under which the data in the file was taken.

Science FPA mosaic data is to be written as a FITS formatted file. Information written to the header of the science data files will incorporate keywords and comments that fully describe the conditions under which the data in the file was acquired. The comments and header keywords are to conform to FITS keyword standards agreed upon by the International Astronomical Union FITS Working Group (see related documents 3, 4 and 5).

11.5.2 Regulatory Design Requirements

None.

11.5.3 Standards Related Design Requirements

Software design and coding should comply with KSD 50 and KSD 210.

11.5.4 Integration Related Design Requirements

None.

12 INTERFACE REQUIREMENTS

12.1 Purpose and Objectives

This section is reserved for interface requirements that are not addressed by other portions of the document.

12.2 Performance Requirements

12.2.1 Parametric Performance Requirements

None.

12.2.2 Operational Performance Requirements

12.2.2.1 Handling

See §8.4.4.2.

12.3 Implementation Requirements

12.3.1 Feature Implementation Requirements

12.3.1.1 Optical Requirements

See §7.3.1.

12.3.1.2 Mechanical

See §8.3.1.

12.3.2 Common Practice Implementation Requirements

12.3.2.1 Glycol Cooling

See §8.3.1.8.

12.3.2.2 Vacuum and Cryogenics

See §8.3.1.9 and §8.3.1.10.

12.3.2.3 Stray Light

See §9.3.2.1.

12.3.3 Standards Implementation Requirements

None.

12.3.4 Regulatory Implementation Requirements

None.

12.4 Design Requirements

12.4.1 Technological Design Requirements

None.

12.4.2 Regulatory Design Requirements

None.

12.4.3 Standards Related Design Requirements

None.

12.4.4 Integration Related Design Requirements

12.4.4.1 Optical Interface

See §7.4.4.1.

12.4.4.2 Mechanical Interface

See §8.4.4.

12.4.4.3 Electrical/Electronic Interface

See §9.4.4.1.

13 RELIABILITY REQUIREMENTS

13.1 Purpose

A process should take place to confirm that the MOSFIRE instrument will provide a high level of reliability for a 10 year lifetime.

13.2 Scope

Unless otherwise indicated all of the requirements of this section apply to all components of MOSFIRE.

13.3 Procedure for Reliability Determination

A recommended procedure to determine the reliability of MOSFIRE is the use of the reliability prediction models for electronic components and systems given in MIL-HDBK-217F-2 "Reliability Prediction of Electronic Equipment" and the reliability prediction models for mechanical components and systems given in the Naval Surface Warfare Center "Handbook of Reliability Prediction Procedures for Mechanical Equipment", NSWC 98/LE1.

The MTBF as determined by the prediction models should then be used to establish the operating period before failure based on a 10 year period as follows:

$$R(t) = \exp^{\left(\frac{-t}{MTBF}\right)}$$

$$\text{where:}$$

$$\text{R(t)} = \text{probability of operation without failure for time t}$$

$$\text{t} = \text{time in hours}$$

$$\text{MTBF} = \frac{1}{\sum \text{(all component failure rates)}}$$

The probability of operation without failure for MOSFIRE is expected to be more than 0.90 for this time period (t = 87600 hours). Software is not included in this requirement or the requested method of reliability assessment. The reliability of the software to be used with MOSFIRE can only be determined by testing.

14 Spares Requirements

Spares shall be provided for all components that are considered “consumable” or are designed with a service life of less than 10 years. For these components the required spares quantity is 20% (or at least 1 unit) of the in service quantity.

15 Service and Maintenance Requirements

MOSFIRE must incorporate provisions for disassembly for servicing of internal components. Handling fixtures and any specialized tools required for servicing must be provided with MOSFIRE. A written procedure accompanied by illustrations must be provided for removal and replacement of all major sub-assemblies in MOSFIRE.

16 DOCUMENTATION REQUIREMENTS

16.1 Documentation Package

The MOSFIRE instrument should be provided with design, operating and maintenance documentation package including, but not limited to, the following:

1. System overview and design description, including details of optical design, mechanical design (including thermal and vacuum design), electrical design and software design. All design documents shall be supplied in revised form as required to reflect the delivered as-built instrument.

2. User's manual, including but not limited to operating instructions.

3. Revised fabrication/procurement drawings, specifications, and schematics that accurately depict the as-built condition of all of the components of the instrument. All such drawings should be detailed enough to allow fabrication of spare parts should the need arise.

4. Bills of material including supplier information for all components of the instrument.

5. A maintenance manual, including all information and procedures needed to maintain and operate MOSFIRE during its lifetime, including but not limited to the following:

    a. Procedures for handling, assembly and disassembly of the instrument and all of its components accurately reflecting the as-built instrument. All assembly instructions shall be clear, and include a tools list, parts lists and check list.

    b. Routine maintenance and inspection procedures, as well as a maintenance schedule.

    c. Alignment procedures.

    d. Troubleshooting guide.

    e. Repair procedures.

6. Acceptance Test Plan documents, test procedures and all performance data and results of acceptance testing.

7. Descriptions of all recommend spare parts and procedures for removal and replacement including written procedures and assembly drawings and exploded view drawings.

8. All manufacturer's manuals and documentation for COTS components.

9. All software design documents and related documents including, but not limited to software build and install procedures, source code, release description document, software design document(s), software acceptance testing plans and software user's manual.. All software design documents and related documents shall be supplied in revised form as required to reflect the delivered as-built instrument software.

10. Safety plan and procedures.

16.2 Drawings

16.2.1 Drawing Standards

The primary units for all drawings are the international system of units (SI). All instrument drawings should be dimensioned in millimeters. Secondary dimensions may be provided in inches.

All instrument drawings should conform to the following:

1. Drawings for optical components shall conform to ANSI/ASME standard Y14.18M-1986 "Optical Parts (Engineering Drawings and Related Documentation Practices)".

2. Mechanical drawings shall conform to ANSI Y14.5M-1994 (R1999) "Dimensioning and Tolerancing" and ASME standard Y14.100-2000 "Engineering Drawing Practices".

3. Each sheet shall conform to ANSI Y14.1-1995 (R2002), "Decimal Inch Drawing Sheet Size and Format". Drawing size shall be determined on an individual basis.

4. Each drawing shall have a title block with at least the following information:
   - Development group
   - Drawing number
   - Title
   - Designer
   - Draftsman
   - Scale
   - Method for determining next higher assembly.

5. All drawings shall include parts and materials lists in accordance with ANSI Y14.34-2003, "Parts Lists, Data Lists, And Index Lists: Associated Lists". All items shall be identified with an item number or other label (with reference to the drawing number if one exists) for each part or component with all information required for procurement.

6. Assembly drawings shall include all relevant views required to clearly define the assembly including isometric and exploded views.

7. All detail drawings shall include all views, geometry, dimensions and feature controls required to duplicate the part in accordance with ANSI Y14.5M-1994 (R1999) “Dimensioning and Tolerancing”.

8. Multi and sectional view drawings shall be developed in accordance with ANSI Y14.3M-1994 “Multi and Sectional View Drawings”.

9. Fluid power system schematics shall be drawn in accordance with ASME Y32.10-1967 (R1994) “Graphic Symbols for Fluid Power Diagrams”.

10. Dimensions and tolerances shall be indicated in accordance with ANSI 14.5M-1994 (R1999).

11. Surface finishes shall be described in accordance with ANSI 14.5M-1994 (R1999).

12. The electronic drawing format shall be at least AutoCAD 2000 (or a more current release). Drawings created with other computer aided drafting (CAD) software shall be provided in .dxf files compatible with AutoCAD 2000 (or a more current AutoDesk software release). The preferred CAD software for 3D drawings is AutoDesk Inventor or SolidWorks.

13. The electronic drawing format for electrical/electronic schematics and printed circuit board layouts and assembly drawings shall be OrCAD V9.0 or a more current release. A less desirable alternative is to provide drawings for electrical/electronic schematics and printed circuit board layouts and assembly drawings as AutoCAD 2000 (or a more current release) drawings or as .dxf files compatible with AutoCAD 2000 (or a more current AutoDesk software release).

16.2.2 Required Drawings

All drawings must be provided as specified in the formats listed above and in the native format if translated to one of the specified formats.

The following drawings should be provided:

1. As-built detailed mechanical drawings for all components not commercially available. Drawings shall provide sufficient detail to fabricate the components to original design intent.

2. As-built detailed drawings for all optical components not commercially available. Drawings shall provide sufficient detail to fabricate the components to original design intent.

3. As-built assembly drawings for all assemblies not commercially available along with appropriate detail drawings and assembly tolerances and procedures.

16.3 Electrical/Electronic Documentation

The following documentation for all electrical and electronic assemblies and modules in the instrument should be provided:

1. A top level system block diagram.

2. An interconnection diagram showing all interconnecting cables and connected assemblies and modules in the instrument.

3. An interconnection diagram showing the external connections to the instrument.

4. Pinouts and wire color codes for all internal and external connectors and cables.

5. Schematics, assembly drawings, bills of material, printed circuit board designs and printed circuit board artwork for all custom printed circuit boards in the instrument.

6. Programmable logic device source code for all programmable logic devices used on custom printed circuit boards in the instrument.

7. Programmable logic device source code for all programmable logic devices used in COTS components where the programmable logic device source code has been modified or customized for the instrument.

8. Configuration, set up and/or switch/jumper setting information for all COTS components.

16.4 Software

The instrument software is defined as all host, target, embedded controller software (including detector controller code) and data reduction software for the instrument including the code for servo controls such as DSP code, PMAC code or other motion control code and the like. The following software data files and documentation should be provided:

1. Source code for all instrument software on CD/DVD.

2. Executables for all instrument software on CD/DVD.

3. One copy of any and all software libraries required to build the instrument software executables on CD/DVD.

4. A list of any and all code compilers required to build the instrument software.

5. All makefiles required for building the instrument software on CD/DVD.

6. All configuration files and all data files read by the instrument software executables at start-up time on CD/DVD.

7. Any scripts required to run the instrument or the data reduction package on CD/DVD.

8. Any aliases, environment variable definitions, etc. required to correctly set up the environment to build or run the instrument software on CD/DVD.

9. For any models developed for simulation of the instrument including optical designs and control loops the model code and data shall be supplied. The preferred software for optical design is Zemax. The preferred software for control loop simulations and models is Matlab or IDL.

10. For all software control loops full design documentation must be provided including block-diagrams, transfer-function models of the system, performance criteria and analyses to show how the control loop design satisfies the requirements. Models and simulations of the control loops should also be provided.

11. Documentation for the instrument software, consisting of:

    a. Users Manual: a detailed tutorial describing how to use this version of the software.

    b. List of Source Code: A hierarchical list of all directories, source files, include files, libraries, etc that can be used as a checklist for new releases.

    c. Functional Descriptions: a description of each routine or module describing its function.

    d. Startup/Shutdown procedures: descriptions of the steps necessary to cold start the system and the steps necessary to safely shut down a running system. This document should include descriptions of any configuration files required at start-up time.

e. Installation Manual: a detailed description of the steps necessary to rebuild and install the system from sources.

f. Troubleshooting Guide: A description of the techniques for tracking down failures, checking system health, killing and re-starting portions of the system without a full reboot.

g. Software Test Procedures: a detailed description of how to run the software acceptance tests.

h. Programmer's Manual: This document shall include a description of the theory of operations; data and control flow and how standard functionality can be extended (e.g. add a new command to the API).

17 GLOSSARY

Table 19 defines the acronyms and specialized terms used in this document.

Table 19: Glossary of Terms

Term	Definition
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers International
ASTM	ASTM International
ATA	Air Transport Association
CARA	California Association for Research in Astronomy
CCR	Closed Cycle Refrigerator
CENELEC	European Committee for Electrotechnical Standardization
CSEM	Centre Suisse d'Electronique et de Microtechnique (Swiss Center for Electronics and Microtechnology)
CFR	Code of Federal Regulations
CIT	California Institute of Technology
COTS	Commercial Off The Shelf
CSU	Configurable Slit Unit
CVCM	Collected Volatile Condensable Materials
dBA	Sound level in decibels, measured using the A contour frequency weighting network
DCS	Drive and Control System
DEIMOS	DEep Imaging Multi-Object Spectrograph
EIA	Electronic Industries Alliance
EMI	Electro Magnetic Interference
FOV	Field Of View
FPA	Focal Plane Array
FWHM	Full Width at Half Maximum.
IBC	International Building Code
ICC	International Code Council
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
KSD	Keck Software Document
MOSFIRE	Multi-Object Spectrometer for InfraRed Exploration
MTBF	Mean Time Between Failures
NEBS	Network Equipment Building System
NEMA	National Electric Manufacturers Association
NIR	Near InfraRed
NRT2	Nasmyth platform Right Track position 2, (right Nasmyth platform, Keck II)
OSHA	Occupational Safety and Health Administration
RT1	Rail Transport position 1, (Nasmyth deck, Keck I)
SDSU	San Diego State University
SMEDA	Slit Mask Exchange Dewar Assembly
SSC	Science Steering Committee
TBC	To Be Completed
TBD	To Be Determined
TIA	Telecommunications Industry Association
TML	Total Mass Loss

Table 19, continued: Glossary of Terms

Term	Definition
USGS	United States Geological Survey
WMKO	W. M. Keck Observatory
WRT	With Respect To
UCLA	University of California, Los Angeles
UCSC	University of California, Santa Cruz
UPS	Uninterruptible Power Supply
UL	Underwriters Laboratories Inc.