Draft Engineering Guideline
For the Preparation of Requirements Documents

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FOREWORD

The purpose of this guideline is to describe the preferred format for requirements documents at the W.M. Keck Observatory. It provides guidance on the organization and presentation of requirements information and also describes many of the normative requirements for instruments at the observatory.

Requirements documents are normally written at the beginning of the preliminary design phase for a new instrument, and they are an important element of the process of defining and communicating the observatory's expectations for a new instrument. This guideline is intended for use by anyone who authors or contributes to requirements documents. It also is useful to anyone reviewing a draft requirements document as reference to the expected format and normative requirements.

This is the first version of the guideline for requirements documents, and is released as a draft for comment.

The guideline is organized in 17 sections. The first section describes the role of the requirements document in the development process for a new instrument. The second section provides an overview of the requirements document. The remaining sections provide detailed information on the content of the requirements document. A template for the requirements document including normative requirements is included in an Appendix.

Suggestions for changes and additions are always welcome and should be sent to the author:

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1 Role of the Requirements Document

The purpose of the requirements document is to indicate CARA requirements for the design and implementation of a scientific instrument for the Keck Observatory. As the procuring organization, CARA 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 document avoids prescribing specific design or implementation solutions except for those solutions that embody the observatory's unique knowledge or experience. The document establishes requirements for the new instrument that will guide the various design phases of the instrument through to critical design.

The requirements reflect both the analysis of the science need and the proposed solution as provided by the new instrument. The requirements document is developed in the process of establishing a proposed solution to the scientific problem and is part of the documents delivered at the beginning of the preliminary design phase. The requirements document is then refined in the preliminary design and results in a proposed specification for the instrument that is delivered at the end of the preliminary design phase.

The requirements document is structured from the common disciplines that make up a typical scientific instrument for observational astronomy. The requirements document for a particular project is tailored from a general format by deleting sections that do not apply, and adding sections to cover unique requirements.

The conceptual design of a new instrument is expected to develop through a systems engineering approach. In the systems engineering process a "product structure" is defined for the instrument, and from this structure the deliverables are identified and formalized in a Work Breakdown Structure (WBS). The requirements document and the WBS have a matrix relationship. In this relationship elements of the WBS will have associated requirements in a variety of disciplines, and these requirements are described in the requirements document.

2 Overview

The requirements document consists of ten major sections. In each section the requirements may be grouped into three broad categories: performance, implementation and design. Each requirements document may add or delete sections as needed and not every section will have all three of the requirement categories.

2.1 Performance Requirements

Performance requirements are requirements that are expected to later become instrument specification items. Every item in the specification must be able to be tested or verified. Performance requirements must fully define the expected performance of the instrument. They will be the primary driver for all of the design and implementation decisions that will determine how the instrument will meet the future specifications.

Performance requirements are broadly classified as parametric and operational. Parametric requirements are quantitative, and the full description of a parametric requirement must include a definition of the units of measure and the method of measurement.

Operational requirements define aspects of system function or usage. Operational requirements are qualitative, and require a description of the feature and how it functions. The description must include a procedure for determining that the requirements are met. This may consist of testing, analytical examination, inspection or demonstration.

It is important to retain perspective on the nature of performance requirements. The expression of performance requirements reflects the need, but they are not a specification. The requirements document is written at a time in the development process where the exactitude of a specification cannot yet be applied to any of the performance requirements for the instrument. There may be considerable scientific or technical uncertainty for some parameters, and these parameters may only be able to be truly established after some research and testing activities have taken place in the new instrument development project.

In a requirements document the values given for parametric performance requirements may either be a goal towards which the research and development activities for the instrument should aim, or they may be values based on a well established level of scientific or engineering knowledge that are presumed to be achievable in the course of the development program.

Because of the uncertainty that exists for some parametric performance requirements, the requirements document provides for two types of parameters, goals and typical. Typical parameters are used where enough is known to establish a range of values for the parameter. Goal parameters are used where significant scientific or technical uncertainty exists that must be addressed before the range of values can be known.

2.1.1 Parametric Performance Requirements

In the performance requirements part of each requirements document section the typical and goal parameters should be in separate sections. It will be common for typical parameter requirements to directly transition to specification parameters. Goal parameters will not be used in a specification; instead the goal parameters will be refined into specification parameters in the research and development activity for the new instrument.

2.1.1.1 Typical Parameters

Typical parameter values are tabulated as follows:

Parameter	*Min.*	*Typ.*	*Max.*	*Units*	*Notes*

These parameters have a range of values with a statistical mean represented by the typical value. Systems are normally designed to remain functional over the full range of parameter values in the worst-case combinations. It is important to note that the parameter definition must indicate when values in excess of the minimum or maximum value would be a failure to meet the requirements. Maximum and minimum values are inclusive, that is the range of values are greater than or equal to minimum, and less than or equal to maximum.

Typical parameter values will normally be a major element of the specifications, and many of the parameter values in the requirements document will transition directly to the specifications. Verification of the specifications will be performed in the ATP. The parameter values in the specification will be verified through test and measurement, and it is assumed that best current practice will be used when making such measurements. If the test conditions and method of measurement are not obvious they must be specified in the requirements. It is also expected that when the test data is presented the data will be accompanied by a detailed description of the test conditions and methods used.

2.1.1.2 Goal Parameters

Goal parameter values are tabulated as follows:

Parameter	*Goal*	*Min.*	*Max.*	*Units*	*Notes*

The goal value sets the target for achievement of performance, and indicates the need for research and development activity to determine a typical value for the parameter. The minimum and maximum values indicate the bounds on performance beyond which no useful benefit is expected. In some cases goal values may be specified as less than or greater than some value, and maximum or minimum values may not be required.

Goal parameters will not be used in specifications, they will either be deleted from the performance requirements during the design process or they will be refined into typical values for use in a specification.

2.1.2 Operational Performance Requirements

Operational requirements are expressed through a description. This will consist of text, accompanied by figures or drawings as required. Operational requirements may describe specific features, or they may describe how aspects or features of the system are used. These are testable features or functions that are not suitable for parametric description. These features are distinct from those described in the subsequent feature implementation requirements sub-section in that they will appear in the specifications.

Operational requirements that transition directly into a specification must be verified in the ATP. Operational specifications that are to be verified by test or demonstration must include a description of the procedure that will be used to perform the verification. Operational specifications that are to be verified by inspection or analysis must include criteria for the inspection or analysis and must also include the method to be used to evaluate the results of the inspection. This method may include a quantification of the inspection results through a scorecard or some other technique.

2.2 Implementation Requirements

Implementation requirements define the instrument and how it will achieve the performance requirements. Implementation requirements are a secondary driver in the design process and ultimately determine how the instrument will function in its intended use and how it will integrate with the other observatory systems.

There are four classifications for implementation requirements: feature, common practices, standards and regulatory.

2.2.1 Feature Implementation Requirements

Feature implementation requirements define specific features (elements or behaviors) that the system should provide. The broadest use of the feature implementation requirements category is in the overall system definition, which is normally the first major section of the requirements document. Additional feature implementation requirements will be provided in other sections for special cases, or for features that are not obvious from the overall system definition.

Feature implementation requirements are given in the form of descriptions of the element or behavior. Drawings or flowcharts are frequently used to clarify feature implementation requirements.

2.2.2 Common Practices Implementation Requirements

Common implementation practices express the conventional ways of doing things that are peculiar to a certain field of application. These practices are in essence de-facto standards that reflect established solutions for certain system elements or behaviors. The definition of common practices for the implementation of a system ensures that the expected default behaviors are present, and ensures compatibility with established methods and existing systems. Common practices are distinct from interface requirements (which have their own section in the requirements document). Common practices are general in scope and may refer to things such as material choices, types of lubricants, etc.

The common practices requirements are given in the form of descriptions of each practice, along with an explanation of how these practices affect the proposed implementation.

2.2.3 Standards Implementation Requirements

Standards implementation requirements describe features or behaviors that are necessary to comply with formal standards. These may be consensus standards developed by organizations accredited by ANSI or ISO, or they may be in-house standards. In all cases these standards have clearly defined requirements that affect implementation and a clearly defined relationship to verifiable performance requirements.

Standards implementation requirements are given in the form of descriptions that indicate the way in which the feature or behavior must be implemented in order to conform to the standard. Standards implementation requirements always make reference to the associated standards documents.

2.2.4 Regulatory Implementation Requirements

Regulatory implementation requirements describe features or behaviors that are necessary to comply with government regulations. These may be local, state or national regulations and are frequently based on references to, or incorporation of, consensus standards, such as for example the National Electric Code.

In most cases government regulations are tied to standards that have clearly defined requirements that affect implementation and have a clearly defined relationship to verifiable performance requirements that must be met in order to establish compliance with the regulations.

Regulatory implementation requirements are given in the form of descriptions that indicate the way in which the feature or behavior must be implemented in order to conform to the regulations. Regulatory implementation requirements always make reference to the associated laws and standards documents.

2.3 Design requirements

Design requirements describe approaches to the implementation of the instrument that are considered fundamental to achieving the performance requirements. Design requirements typically limit the choice of design alternatives, and can act as constraints on the search for proposed solutions to the scientific need. As such they are used sparingly, but it some cases there are important compatibility or legacy requirements that force the imposition of design requirements. It is also the case that the ability of an implementation to meet certain requirements of standards and regulatory requirements may be impacted by design choices, and requirements in these areas are imposed especially for that reason.

There are four general classifications for design requirements: technological, regulatory, standards related and integration related.

2.3.1 Technological Design Requirements

Technological design requirements describe a preferred design approach to the system, or to problem solving in specific disciplines. These design requirements are accompanied by a justification and appropriate references to scientific or technical literature where available.

Technological design requirements may also include specific technical details such as a particular type of bearing or fastener to be used at a particular point in order to achieve specific engineering results or to meet compatibility requirements.

2.3.2 Regulatory Design Requirements

A Regulatory design requirement describes a design approach that is necessary to comply with government regulations. These may be local, state or national regulations and are frequently based on reference to, or incorporation of, consensus standards, such as for example the National Electric Code.

In most cases government regulations are tied to standards that have clearly defined requirements that affect design and implementation. There are normally clearly defined criteria for demonstrating that the design conforms to the regulations.

Regulatory design requirements are given in the form of descriptions that indicate the way in which the feature or behavior must be designed in order to conform to the regulations. Regulatory design requirements always make reference to the associated laws and standards documents.

2.3.3 Standards Related Design Requirements

A standard related design requirement describes a design approach that is necessary to comply with a formal standard. This may be a consensus standard developed by organizations accredited by ANSI or ISO, or it may be an in-house standard. In all cases these standards have clearly defined requirements that affect design and implementation and a clearly defined relationship to verifiable performance requirements.

Standards related design requirements are given in the form of descriptions that indicate the way in which the feature or behavior must be designed in order to conform to the standard. Standards related design requirements always make reference to the associated standards documents.

2.3.4 Integration Related Design Requirements

Integration related design requirements describe design approaches that are necessary for compatibility with existing observatory systems. These design requirements are accompanied by references to the documentation for the existing system and an explanation of the design issues raised by the need for compatibility.

2.4 Specific Language of a Requirements Document

The requirements document should use language that reflects the function of the document to express needs or wants, rather than the imposition of specifications. This role is appropriate for a document that will guide rather than dictate to a research and development activity. Language that is appropriate to specifications should be avoided in requirements documents. For example, use should instead of shall or will instead of must.

3 Detailed Description of the Requirements Document

A template for a typical requirements document is shown in Appendix A. This template should be used for reference when reading the detailed descriptions that follow. The template provided includes all 16 sections of the requirements document. For each application sections of the requirements document that do not apply may be omitted with the exception of the following:

1 Introduction
2 Scope and Applicability
3 Related Documents
4 Revision History
5 Background
6 Overall System Requirements
10 Safety Requirements
12 Interface Requirements
13 Reliability Requirements
14 Spares Requirements
15 Service and Maintenance Requirements
16 Documentation Requirements
17 Glossary

It should also be noted that safety is located where it is in the document because the safety requirements may be difficult to understand unless the proper context is first established by the preceding sections, particularly the mechanical and electronic/electrical sections. Safety would be the very first section given its overarching importance if it could be usefully read without the information given in other sections of the document.

In the sections that follow the second digit of each section number corresponds to the major section number of the template requirements document.

3.1 Introduction

This section should describe the purpose of the requirements document and the intended audience.

3.2 Scope and Applicability

This section should clearly state what deliverable(s) are covered by the requirements of this document. The release date and revision level should also be stated. The draft or final status of the document should also be clearly indicated.

3.3 Related Documents

This section should cite all related documents or publications. Citations should be in a consistent style, the Modern Languages Association (MLA) style is recommended. References to documents available in print form are preferred, but web page references may be used where necessary provided that the URL given is tested.

3.4 Revision History

The revision history should be indicated in a table as follows:

Revision	Date	Author(s)	Reason for revision / remarks
1.0	April 14, 2003	SMA	Original Issue

A new line is added to the table with each revision.

The revision numbering starts at 1.0 and increments every circulated version. The minor digit indicates that edits or corrections have been made to text, figures or tables. The major digit is incremented when significant portions (more than a sentence in any section) of text are added or deleted or when tables or figures are added, replaced or deleted.

3.5 Background

This section should describe the background of the new instrument. It should include a brief description of its motivation and origins, and this section should list the organization(s) and key personnel involved in its development.

3.6 Overall System Requirements

3.6.1 Introduction

This section and many of those that follow will consist of requirements organized as described in section 2. Each section must have the three major second level sections: performance

requirements, implementation requirements and design requirements. If a section is not used then the section simply contains the following text (using optical design requirements as an example):

"There are no optical design requirements."

Each of the three second level sections may contain one or more of the third level sections. Third level sections that are not required may simply be omitted. Although it is believed that the sections provided for in this guideline will meet virtually all of the needs for a requirements document additional sections or sub-sections may be added where a strong justification exists.

The complete outline of sub-sections for each requirements section is as follows:

```
#       [   ] Requirements

#.1     Performance Requirements
#.1.1       Parametric Performance Requirements
#.1.1.1         Typical Parameters
#.1.1.2         Goal Parameters
#.1.2       Operational Performance Requirements

#.2     Implementation Requirements
#.2.1       Feature Implementation Requirements
#.2.2       Common Practices Implementation Requirements
#.2.3       Standards Implementation Requirements
#.2.4       Regulatory Implementation Requirements

#.3     Design Requirements
#.3.1       Technological Design Requirements
#.3.2       Regulatory Design Requirements
#.3.3       Standards Related Design Requirements
#.3.4       Integration Related Design Requirements
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Figure 1: Requirements Sub-sections

In figure 1 the "[ ]" is replaced with the section title (overall, optical, etc.). The "#" is replaced with the outline number for each section (using the "heading1" style in the template document). As discussed above sections #.1, #.2 and #.3 are mandatory.

3.6.2 Content of the Overall Requirements Section

3.6.2.1 Performance Requirements

This sub-section of the overall requirements section will include requirements related to the operating environment for the instrument: temperature, humidity, dust and debris, altitude, shock, vibration and so on. Performance requirements that apply to every sub-system or design discipline may also be included in this section.

3.6.2.2 Implementation Requirements

This section should describe the overall features and functions of the instrument. This is the place to describe (in the feature implementation requirements section) how the instrument is organized and how it integrates with the other observatory systems. The common practices section may also be use to describe observatory operating practices or requirements that are important to consider in the implementation of the new instrument.

3.6.2.3 Design Requirements

This section may be used to reinforce important principles of system design that should be followed in the development of the instrument. Overall detail design issues may also be discussed here if they apply to all of the sub-systems and disciplines in the instrument. This section should be used sparingly.

3.7 Optical Requirements

This section should contain all of the requirements for the optical systems in the instrument. This includes the optical performance of any imagers or detectors. It may be difficult at times to separate mechanical requirements from optical requirements where things like alignment and mounting are concerned. The choice should be guided by what makes the requirements document easier to understand.

The same can be said for the close interdependence between the detectors themselves and the controlling/digitizing electronics. In this case it is likely that some overlap will exist between the detector requirements in the optical section and the detector and detector electronics in the electronics section.

3.7.1 Performance Requirements

This section should describe all of the optical performance parameters, which will include items such as:

- Wavelength range(s)

- Throughput
- FOV/plate scale/etc.

Specific parametric requirements for wavefront quality, alignment and aberrations will also be included here.

For detectors all of the common parameters will be described which will include:

QE, CTE, dark current, noise, PSF, cosmetic quality, etc.

3.7.2 Implementation Requirements

This section describes the implementation requirements for the optical system, and includes basic descriptive material such as the type of optical system: spectrograph, imager, etc.

The expected telescope optical configuration should also be described, particularly the mounting position, f number, input focal plane location, etc.

The materials, architecture and format of detectors would be described here as well.

The standard practices section might identify for example, particular optical coatings or optical element mounting techniques that are important to use (or avoid) in building instruments for operation at the summit of Mauna Kea.

3.7.3 Design Requirements

This section describes the specific details of optical design that are considered essential to achieving the desired performance. There may be system compatibility or integration requirements (such as the f number of the telescope system or its focal plane curvature) that are essential to understand in order to achieve the required performance. As previously mentioned this section should be used sparingly.

3.8 Mechanical Requirements

This section should contain all of the mechanical requirements for the instrument.

3.8.1 Performance Requirements

Parametric performance requirements may include:

Physical characteristics
- dimensions, tolerances, fit, weight, etc.

Tolerance for vibration and shock

Seismic ratings

Component ratings
- Wear margins
- Safety margins
- Expected lifetimes

Flexure

Paints and finishes, corrosion resistance

3.8.2 Implementation Requirements

Implementation requirements include specific mechanical features such as mounting or hoisting points, handling facilities, covers and internal access provisions. In this regard there may be some overlap with requirements in the electrical/electronic section for service access and implementation issues such as connector mounting and strain relief. Again, the choice of which section to describe these should be guided by what makes the requirements document easier to understand.

Similarly there will be overlap with the optical section in regards to provisions for mountings and adjustments for example. The same logic of making the requirements document easy to understand should prevail.

Specific items that should appear in the mechanical implementation requirements include:

- Fit and Finish
- Paint types and colors
- Platings
- Types of fasteners
- Types of bearings
- Lubricants
- Mounting provisions and defining points
- Handling provisions
- Accessories

3.8.3 Design Requirements

This section describes the specific details of mechanical design that are considered essential to achieving the desired performance. There may be system compatibility or integration

requirements that are essential to understand in order to achieve the required performance. As previously mentioned this section should be used sparingly.

3.9 Electronic/Electrical Requirements

3.9.1 Performance Requirements

3.9.2 Implementation Requirements

3.9.3 Design Requirements

This section describes the specific details of electrical or electronic design that are considered essential to achieving the desired performance. There may be system compatibility or integration requirements that are essential to understand in order to achieve the required performance. As previously mentioned this section should be used sparingly.

3.10 Safety Requirements

3.10.1 Performance Requirements

3.10.2 Implementation Requirements

3.10.3 Design Requirements

3.11 Software Requirements

3.11.1 Performance Requirements

3.11.2 Implementation Requirements

3.11.3 Design Requirements

3.12 Interface Requirements

3.12.1 Performance Requirements

3.12.2 Implementation Requirements

3.12.3 Design Requirements

3.13 Reliability Requirements

3.14 Spares Requirements

3.15 Service and Maintenance Requirements

3.16 Documentation Requirements

3.17 Glossary

This section consists of a table that defines the acronyms and specialized terms used in the requirements document.