Telescopes

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C.1. INTRODUCTION

The purpose of this section is to describe the telescope subsystem, starting with a functional description and followed by a list of the requirements. After the requirements are presented, the procurement strategy will be outlined along with an evaluation of contractor responses and a discussion of an alternate procurement approach. Finally, risks will be assessed and a summary of the section provided.

C.2. SUBSYSTEM DESCRIPTION

The system baseline design includes seven telescope subsystems, with one telescope on each of the legs capable of being relocated to another position within the chosen Y configuration. An alternate option being considered is the procurement and installation of 10 fixed telescope subsystems. The primary issues involved with this decision are cost and reliability. It is the diversity of scientific requirements that has driven the design to accommodate two types of configurations, one a closely packed distribution and the other a more widely spaced distribution with longer baselines.

The telescope subsystem is comprised of (1) the telescope assembly, (2) enclosure assembly, (3) subsystem controller, (4) power assembly, (5) optional high order wavefront correction assembly, and (6) optional laser assembly. The telescope subsystem is shown schematically in Figure C.1, a hardware tree is shown in Figure C.2, a configuration drawing is given in Figure C.3, and an optical diagram of the telescope subsystem is presented in Figure C.4. Each of these six assemblies will be discussed in more detail in the text that follows.

At the present time, no detailed technical information will be presented on the transportation equipment that may be required to move a telescope subsystem, or parts of a subsystem, from one location to another. While this equipment would be part of the telescope subsystem, how it fits in the subsystem hardware tree is design dependent and the design options/cost estimates are not sufficiently complete to properly integrate the best design into these drawings.

C.2.1. Telescope Assembly (1A1)

The telescope assembly is that portion of the subsystem that most people would consider "the telescope". The telescope assembly consists of the telescope tube, elevation mount, and azimuth mount subassemblies as shown in the hardware tree of Figure C.2. While the baseline design assumes an alt-az type of telescope, potential telescope subsystem contractors have been encouraged to look at all types of telescope configurations in an attempt to meet both the cost and technical requirements for this very specialized application. Of particular interest are the recent designs developed by ESO for their interferometric telescopes used in conjuction with the 8 m telescope array. The problems with developing new telescope designs for this particular application are the additional design and prototyping costs,

FIGURE C.1. Telescope subsystem block diagram.

and the unknown reliability and problems associated with a design that has no operational history.

The telescope tube subassembly includes the primary mirror (M1); the secondary mirror (M2); the drive motors, electronics, and mechanisms required to position the secondary mirror in five degrees of motion (2-axis lateral motion, 2-axis tilt, and focus); a tertiary mirror (M3); and a metering structure to provide a structural framework to hold all the above parts in their proper locations. The primary mirror in the baseline design was chosen, for scientific and cost reasons, to be approximately 100 cm in diameter. The secondary mirror was chosen to be 12.5 cm in diameter. The primary/secondary combination provide an afocal optical system having a 100 cm input beam diameter and a collimated 12.5 cm output beam diameter, as shown in Figure C.3. This afocal system reduces the input beam by a factor of 8 (magnification = 0.125). While the actual magnification is somewhat arbitrary, the value chosen is a compromise between the effects of diffraction versus beam diameter, technical feasibility, and system costs versus beam size. From a cost standpoint, it is advantageous to reduce beam size as much as possible as soon as possible. But to minimize wavefront degredation due to diffraction, it is necessary to keep the beam diameter at a reasonable size. An analysis of wavefront degredation versus beam diameter is given in Appendix E. The effects of system primary/secondary alignment on wavefront quality are of concern both from a technical standpoint, but also from an operational standpoint. An analysis of wavefront degradation as a function of alignment errors (decentering, tilt, and focus) for different field positions made at GTRI by Allen Gilbert indicates that these alignment errors need to be controlled. Alignment control will occur through a combination of structural/thermal design, real time alignment control, adaptive optics, and observing techniques. Some scientific measurements will be more sensitive to alignment errors than others. Knowledge and experience of the observer(s) will help to optimize the operational

FIGURE C.3. Telescope subsystem configuration drawing.

FIGURE C.4. Telescope subsystem optical layout.

FIGURE C.5. Alt-az telescope mount designs.

observing program in most situations.

The elevation mount subassembly includes the elevation mount structure, elevation bearing(s), elevation drive motor(s), elevation encoder, a steering mirror (M4), steering mirror drive electronics, an optional fixed mirror and mount (M4) to replace the steering mirror in case of steering mirror malfunction, and turning mirrors (M5) and (M6). As discussed above, the baseline design includes an alt-az design, but potential contractors are encouraged to use any design which meets the technical specification and is cost competitive. Of the several variations of the alt-az design that exist, the baseline design uses type (a) of Figure C.5. This design was chosen because it appears to minimizes the amount of wavefront piston introduced into the beam train when the telescope jitters about the azimuth axis due to wind shake or tracking jitter. The disadvantage of this design is that it requires two additional mirror reflections.

Various bearing types have been discussed with some of the telescope contractors and it is likely that a mechanical type bearing, as opposed to an air bearing or oil pad bearing, will be used for the elevation axis. An air bearing having the lateral stiffness required for this application is not a standard unit and the cost is prohibitive. An oil pad bearing generates heat at a location which is difficult to remove and increases the complexity of the assembly. Mechanical ball and roller bearings, while simple and relatively inexpensive, typically produce more rotational and lateral jitter than air and oil bearings. This jitter directly affects the servo design of the telescope drives and steering mirror, and ultimately the tracking jitter produced by the telescope.

The type, location, and coupling of the elevation drive motors and encoders will be determined by the telescope contractor; however, the most important aspects of the drive/encoder subassemblies are the ability to produce smooth, jitter free, motion and fairly high incremental resolution.

In order to relax the high frequency response required from the telescope drives and to implement the capability of correcting for full aperture wavefront tilt produced by the atmosphere, the baseline design includes a two-axis steering mirror (M4) as shown in Figures C.3 and C.4. Because of the specialized nature of this unit, the steering mirror and associated drive electronics will probably not be part of the telescope subsystem procurement; however, these components are part of the telescope subsystem and will be considered in the design of this subsystem. The steering mirror could have been located at a number of positions in the optical train, including the secondary mirror. The fact that the secondary mirror, in the baseline design, may have a low frequency (less than 10 Hz) two-axis steering capability is probably of little use for this application because of the associated focus change. A flat steering mirror at the location shown in the baseline design may introduce a piston change in wavefront phase, but not a wavefront curvature resulting from a focus change. The present location (M4) was chosen for the steering mirror, to minimize lateral beam walk, to allow for a stiff support structure to minimize the effect of mirror reaction forces, and to overcome obscuration effects and thermal effects presented at some locations. The specifications for the steering mirror have been developed at CHARA by T. ten Brummelaar. A number of contractors have been contacted with a Request for Information (RFI) package, and several responses have been received. A make/buy decision on this unit will be made in the next phase of the project. The two tilt axes of the steering mirror will be controlled by wavefront tilt error signals originating from an image position sensor located in the visible fringe tracker subsystem (1E). Because the steering mirror is a complex dynamic unit with a finite mean-time-between-failures (MTBF), a fixed-mirror replacement and a spare steering mirror are also being considered. Because of the redundancy of the telescope subsystems, only one spare fixed or steerable mirror assembly would probably be required to support all elevation mount subassemblies.

Mirrors M5 and M6 are relatively simple optical flats mounted in stable mirror mounts. M7 is a flat mirror mounted in a kinematically relocateable mount. The position of the mirror, as shown in Figures C.3 and C.4, depends on implementation of the high order wavefront correction assembly. If a high order wavefront correction assembly is not used, M7 will be located to direct the output from M6 directly into the beam transfer subsystem. If the wavefront correction assembly is implemented, M7 will direct the light from M6 onto the deformable mirror (DM) of the adaptive optics assembly.

The azimuth mount interfaces the elevation mount with the earth. The azimuth bearings may be of any of the three types discussed previously. The final choice of bearing type will be made by the telescope contractor in a fashion consistent with the technical specifications and cost requirements of the project. Again, the important technical issue to be satisfied for bearing selection is smoothness. Azimuth drive motor and encoder type, location, and coupling will be determined by the telescope contractors in a fashion consistent with the telescope subsystem specification and cost factors. Also included as part of the azimuth mount subassembly is the pier which supports the telescope tube, elevation mount assembly and azimuth mount assembly.

C.2.2. Enclosure Assembly (1A2)

As indicated in the hardware tree of Figure C.2, the enclosure subassembly includes a housing or dome, drive motors and electronics, enclosure louvers/fans for environmental control inside the housing, a video monitoring unit, an audio communications unit, and the foundation for the enclosure.

The housing can be designed in many ways. One traditional design uses a dome that rotates on a cylindrical wall and has a slit in the dome that opens to allow the telescope to view the sky. Another traditional design incorporates sheds or quonset type structures that roll away from the telescope, thus exposing the telescope to the sky. In recent years, the effect of enclosure-generated seeing problems has become an important topic of discussion. As a result of this renewed interest in the effects of enclosure design on wind buffeting and seeing, and the non-significant cost of enclosures, many new concepts and theories have been developed. Unfortunately, many of these have not been implemented and fully tested, therefore a certain degree of risk is associated with these new approaches and development costs may also be high. The telescope subsystem specification defines the top level requirements for the enclosure. It has been left up to the telescope contractors to provide the optimum enclosure design based on the specification given them. The basic requirement for the telescope enclosure are to provide environmental protection for the telescope subassemblies during non-operational periods, to provide wind protection during operational periods, and to minimize the seeing effects caused by the enclosure. The foundation for the enclosure must be designed and fabricated in a manner that will minimize the coupling of wind loads, particularly gusts, into the telescope pier during operational periods and thermal transfer of energy at any time.

Enclosure drive motors/actuators and associated electronics are required to position the enclosure and portions of the enclosure. Control of these motors and actuators will be supplied by the telescope subsystem controller, upon command from the system control computer. Appropriate safety interlocks will be installed to protect equipment and personnel. Remote and automated control will be used during normal operational periods. Local control will be available for equipment installation and long-term maintenance.

Enclosure louver/fan units have been listed as a separate unit because of the special requirements needed for this application and because many of the suppliers of enclosures and telescopes do not provide adequate equipment and controls for this application. In an attempt to control the environment of the telescope subsystem during operation, care must be taken to not make matters worse. Control of louvers installed in the walls of the enclosure to regulate wind force and ventilation must not themselves generate heat or detrimental air currents. Likewise, fans installed in piers to flush the telescope optics and structure must not introduce direct or accoustically coupled vibrations into the telescope structure.

Because the telescope subsystems are located at an appreciable distance from the array control console, local monitoring of the operation of the subsystem requires the use of a video monitoring system which includes a commercial CCTV video camera with remote control pan and tilt features. In addition to normal monitoring activities, this system might also be used as part of a security system. Also of importance for monitoring purposes, but more important for communications during initial installation and routine maintenance activities, is installation of a suitable audio communications system.

C.2.3. Subsystem Controller (1A3)

Local control of the telescope is provided by the subsystem controller. The subsystem controller handles all of the normal telescope and enclosure control functions; stores and updates pointing maps for the telescope assembly it controls; provides subsystem level diagnostics, general housekeeping functions, and a human interface; and sends and receives system level communications and control commands over a fiberoptic Ethernet LAN to/from the system control computer.

Depending on the final choice of contractor and maturity of that contractor's design, the telescope subsystem controller and controller software may not conform to the computer standards adopted by the CHARA Array design team. It is probable that the more cost competitive contractors will propose the use of existing hardware and software designs to minimize development costs and maximize reliability. It may be more advantageous for the contractor to modify their existing hardware, software, and documentation to meet the subsystem requirements rather than insist on the development of new hardware and software that meets the computer standards established for the CHARA Array. However, in either case, the hardware, software, and documentation must meet good engineering practices and fit within the framework of our design practices.

C.2.4. Subsystem Power Assembly (1A4)

This subassembly receives power from the site power distribution network and provides internal switching, control, and distribution; surge and transit voltage protection; and provides uninteruptible power for specific functions. Uninteruptible power supplies (UPS) are provided for the controller and enclosure motor drive units to allow the telescope subsystems to achieve a proper storage condition in the event electrical power becomes unavailable during an operational period. The architecture and distribution of the UPS power have not been fully analyzed at this time, and it may be that the final design uses larger global units that provide power for all the hardware requiring UPS power.

C.2.5. High Order Wavefront Correction Assembly (1A5) - Optional

In keeping with the recognized advantages and improvements associated with the correction of static and dynamic high order wavefront abberations, the design of the telescope subsystem will accommodate the hardware necessary to implement these technologies. As in the case of the steering mirror (M4), it is unlikely that any of the telescope subsystem contractors will be in a position to offer a cost effective and technically compliant wavefront correction assembly for the telescope subsystem. It is more likely that this assembly will be developed by the CHARA Array design team in conjunction with one or more subcontractors. A discussion of the requirements of a high order wavefront correction assembly for this application is discussed in Appendix S.

If the wavefront correction assembly is implemented as shown in Figures C.3 and C.4, mirror M7 will direct the light from M6 onto the deformable mirror (DM) of the adaptive optics assembly. The DM (M8) will apply phase correction to the wavefront and direct the beam into the beam transfer subsystem. The amount of conjugate wavefront correction to be applied by the DM (M8) is determined by measuring the amount of deformation in the wavefront sampled with beamsplitter (BS). Mirror M9 is used to direct the sampled beam into the wavefront sensor. In addition to the wavefront sensor, a wavefront reconstructor will be required to calculate the proper wavefront correction and generate wavefront error signals for the DM driver electronics. The type of wavefront sensor (WFS) and wavefront reconstructor to be used has not been determined at this time.

C.2.6. Laser Assembly (1A6) - Optional

The laser assembly is another optional assembly which is implemented only if a high order wavefront correction assembly is operational and only when the brightness limit of the array must be extended. The baseline design shown in Figures C.3 and C.4 indicate that the laser transmitter is mounted on the side of the telescope tube assembly and the laser output is directed, with discrete optical components, to a position behind the secondary mirror where it is transmitted coaxially with the optical axis of the telescope tube assembly. Because of

TABLE C.1. Telescope specifications.

Top Level Requirement	Specification
Telescope optical design	Afocal beam reducer
Collecting aperture	100 ± 1 cm
Telescope demagnification	0.125 ± 0.002
Accumulated wavefront error	0.1 radians
Wavelength coverage	0.5 to 0.8 μm (visible), 2.1 to 2.5 μm (IR)
Throughput	$\geq$0.85
FOV	Full performance over 1×10^{-5} rad (2″) dia., degraded performance acceptable out to 1×10^{-3} rad (206″) dia.
Sky coverage	Z=0.5° to 50° , 360° azimuth
Repointing speed	High speed $\geq$2° /sec, Intermediate speed = 250$\pm$100 arcsec/sec
Max repointing acceleration	0 to high speed in 5 sec.
Max settling time	high speed to final position in $\leq$5 sec
Pointing error (absolute)	$\leq$5 arcsec dia. circle
Incremental pointing resolution	$\leq 5\times10^{-6}$ rad (1 arcsec)
Incremental pointing speed	$\geq$16.5 arcsec/sec
Max tracking speed	$\geq$16.5 arcsec/sec
Closed loop tracking error	$\leq$ 0.16 arcsec relative to command position
Tracking jitter	$\leq 1\times10^{-7}$ rad/sec (0.02″/sec)

gravitational flexure and thermal changes, at least one of the mirrors in the output laser path must be a steering mirror to keep the laser pointed in the proper direction. The type of "laser guide star", including wavelength and spatial distribution, that would best meet the requirements of the CHARA Array project has not yet been fully explored. Advantages of using a laser guide star are discussed in Appendix Q.

C.3. TELESCOPE SUBSYSTEM REQUIREMENTS

The requirements of the telescope subsystem were derived directly or indirectly from the system specification and are formally documented in the Telescope Subsystem Specification (Specification 1A), dated 13 December 1993. This specification is still in draft form and has not been officially released. The telescope subsystem specification was written as an equipment specification, not as a design document. The purpose of the document is to define the requirements, not how to satisfy the requirements. The telescope subsystem specification follows the same general format established by the CHARA Array system specification.

The telescope subsystem specification is divided into a number of sections, but the sections that are most important for this report are those dealing with performance, physical, operational, and environmental characteristics. The remaining parts of the specification outline requirements in other important areas related to design and construction practices, documentation practices, quality assurance procedures, and other miscellaneous issues. These performance requirements given in the telescope specification are summarized in Table C.1.

Note that some of the specifications may not have been updated to reflect their final values.

In some cases, the value in the specification may not be the latest value determined as part of the iterative design analysis process.

The draft telescope subsystem specification was used as the basis for the request for information (RFI) released in May of 1993. During the RFI process, many of the specifications were updated and/or changed as a result of discussions with the contractors responding to the RFI. A description of the RFI package and the results of the process is described next.

C.4. PROCUREMENT STRATEGY FOR TELESCOPE SUBSYSTEMS

Most ground-based astronomy groups have, in the past, acted as the prime or general contractor when building observatories (telescope, optics, enclosure, etc.). These projects have, for the most part, been successful because the systems were relatively simple, schedule was of little importance, a large engineering infrastructure was developed to manage the technical aspects of coordinating a single design between a number of subcontractors, or all of the above. Traditionally, the telescope assembly was procured from contractor A, the optics were produced in-house or purchased from contractor B, and the enclosure was procured from contractor C. In this process, the astronomy group would act as general contractor and be responsible for integrating all the pieces and making it work. For the CHARA Array team, the most effective and potentially least expensive approach is to subcontract the design, fabrication, testing, and integration of the telescope subsystem to one contractor based on comprehensive and verifiable specifications. The telescope subsystem is a candidate for this procurement approach because little or no development is required and insertion of new technology is not required. In fact, the budget constraints for the telescope subsystems may require, for the most part, that contractors use existing designs or that the contractor can develop a new design fairly inexpensively and produce and test the new design economically. However, because of the strong traditional approach to building ground-based observatories, many of the conventional ground-based "telescope" contractors, with a few exceptions, feel uneasy about providing the entire subsystem. Many of the "aerospace" contractors have the engineering breath and management capabilities to accomplish the task, but do not have proven designs for this application and therefore tend to be more expensive.

C.4.1. Request for Information (RFI) Process

The preferred procurement approach for the telescope subsystems is to purchase the subsystems from one subcontractor. This decided, a request for information (RFI) package was developed to start the procurement procedure. Because of the formal communications constraints associated with an official request for proposal (RFP), it was decided to use the RFI as a means of starting communications with the various potential contractors on a more informal level. This approach serves several purposes: to notify various contractors of our intent to procure the subsystems; to allow for free exchange of technical and programmatic information between the contractors and the CHARA Array team; and to allow the contractors and the CHARA Array team a chance to explore various possibilities that might produce a better and more cost effective product for the CHARA Array.

The initial RFI package consisted of: an introductory letter inviting the contractor to participate in the RFI process with the goal of eventually submitting a formal technical, schedule, and cost proposal for the telescope subsystems; a schedule for the RFI process; a draft specification for the telescope subsystem; and a document entitled "Specification Comments" which described the rationale behind the various specifications and solicited recommendations from the contractors on some of the specifications that had not been determined at that time. The introductory letter included information about the estimated schedule for producing the telescope subsystems and an estimate of what cost had been allocated for procurement of the telescope subsystems. The initial RFI package was sent to potential contractors in late May 1993.

Many helpful and constructive comments were received from the contractors during the four weeks following release of the RFI package. As a result of the contractor's comments and questions, revisions were made to the specifications, along with updates to the "Specification Comments" document. This new information was sent to the contractors at the end of June 1993. By this time, a number of the initial interested contractors decided this project did not really fit well with their business goals, product lines, or financial capabilities. Those contractors still interested in the project continued to work with the CHARA team throughout June and July. In the beginning of July, an extensive questionnaire was sent to the remaining contractors. The questionnaire requested the contractors to furnish information about their proposed design, schedule, and cost. Concurrent with receiving replies from the questionnaire, a number of the U.S. contractors were visited.

C.4.2. Contractor Participation

The original RFI package was sent to the 18 contractors listed in Table C.2. These contractors were encouraged to identify if they were interested in providing the entire subsystem or only a specific part of the subsystem. For those contractors only interested in providing a portion of subsystem, an attempt was made to put some of the contractors together for the purpose of teaming and bidding the entire subsystem.

TABLE C.2. Potential telescope contractors.

Contractor	Person Contacted
Andrew Kintec	Bruce Harting
Autoscope	David Genet
Carl Zeiss	Fritz Merkle
Contraves	Robert Anderson
Cranfield Precision Engineering	Brian Clarke
DFM Engineering	Frank Melsheimer
Fair Optical	Gene Fair
G.I.E. Telas	Luc de Rancourt
Hughes Danbury Optical Systems	Terry Facey
L&F Industries	David Chivens
Litton/Itek Optical Systems	Richard Vyce
Lockheed	David Leary
National Optical Astronomy Obsy	Larry Daggert
REOSC	Jacques Guerain
Space Optics Research Lab	Fred Kingsley
TIW Systems	Louis Becker
Univ. of Arizona	John Wilburn
Westinghouse Elec	Dave Ohst

Of the above list, only one contractor failed to respond to the initial RFI package. Of those that responded to the initial package, several contractors decided they were only interested in part of the subsystem, some decided they could not come close to our budget allocation for the subsystem and dropped out, and a few decided they were not interested in building 1m size telescopes. Of those contractors remaining, two contractors felt they would have to have a study contract to develop answers to the questionnaire.

The biggest concern voiced by the majority of contractors was the amount of money budgeted for the procurement of the telescope subsystem. For this RFI, the contractors were given a budget goal of \$2.1 M – \$2.7 M, for all telescope subsystems (installed) with a fixed price contract. Assuming seven subsystems, this amounts to a maximum of \$385 K per subsystem. While this amount is low compared to previous projects, a number of contractors have indicated they can meet both the technical and cost goals we have established.

The technical issue that was least addressed by the contractors was the issue of transporting telescope subsystems from one station to another. However, a few contractors developed techniques for moving all or portions of the subsystems. Some of the approaches involved moving only a portion of the subsystems and duplicating the portions not moved. Some contractors provided cost estimates for building ten subsystems instead of building seven subsystems with three moveable. Most of the technical designs were fairly traditional, but a number of designs were modified in clever ways to provide better performance or lower manufacturing costs.

C.4.3. Preliminary Evaluation of Responses

To maintain a fair and unbiased procurement and to protect any proprietary information received from the contractors, each contractor has been randomly assigned a letter of the alphabet between and including A–R. This letter will be used in place of the contractor's name for this section of the report and in any discussions pertaining to cost or budget estimates included in this report.

Table C.3 shows an evaluation of the responses from the RFI package. The contractors were evaluated in several categories. The ratings for each category are in the range of 1-5, where 5 is the best. The contractors were evaluated relative to each other, so there is a whole spectrum of ratings used. In instances where no information was obtained from the contractor, or where the contractor did not respond to the final questionnaire, a "–" was entered into the table. The lack of response to the RFI does not necessarily mean that this contractor will not respond to a formal RFP in the future, but it may indicate a low probability.

In addition to the evaluations, each category carries a certain weight depending on the perceived importance of that category to the success of the project. The importance of the categories are relative and the whole spectrum of ratings are used. All categories are important to the success of the project, some just more than others. Table C.3 shows the weighting factor applied to each category and the total accumulated score for each contractor. The weighting factors are in the range of 1-5, where 5 is the most important category. The evaluation score for each contractor in each category is determined by multiplying the corresponding rating from Table C.3 with the weighting factor. The cumulative score for each contractor is the sum of the weighted evaluations for that contractor.

C.4.4. Alternate Procurement Approach

As stated in the previous section, the biggest concern of the contractors responding to the RFI, was the cost allocated to procurement of the telescope subsystems. If none of the contractors felt they could provide the complete telescope subsystem and meet the

TABLE C.3. Contractor responses to RFI and weighted evaluations.

Contractor	Technical	Cost	Schedule	Credibility	Cooperation	Cumulative Rating	Notes
A	5	4	4	5	3	65	1
B	5	1	4	4	5	51	1
I	4	5	4	3	5	64	1
P	5	5	5	4	5	72	1
R	5	4	5	5	5	70	1
C	–	–	–	–	–	–	2
L	–	–	–	–	–	–	2
O	–	3	–	–	–	–	2,3
D	–	3	–	–	–	–	3
E	–	–	–	–	–	–	4
F	–	–	–	–	–	–	5
N	–	–	–	–	–	–	5
G	–	–	–	–	–	–	6
H	–	–	–	–	–	–	6
K	–	–	–	–	–	–	6
J	–	–	–	–	–	–	7
M	–	–	–	–	–	–	7
Q	–	–	–	–	–	–	7
Weighting Factor	4	5	1	3	2	75 (max.)	

Ratings: 1 = poor, 5 = excellent
Rating Factors: 1 = least important, 5 = most important

Notes:
1 Contractor submitted information requested on questionnaire
2 Contractor did not feel they could come close to cost allocation
3 Required study prior to completing questionnaire
4 Showed no interest in project
5 Showed interest but did not submit response to final questionnaire
6 Showed interest but project not compatible with business plan
7 Only interested in providing a portion of the project

cost goals given in the RFI, the CHARA Team would have been forced into the position of general contractor for the development of the integrated subsystem. However, since a number of contractors showed the capability and desire to supply the integrated subsystem and several met or were close to the targeted cost goal, it seems appropriate to assume that the telescope subsystems will be procured from a general contractor. The final decision will, of course, have to be made after evaluation of contractor responses to the formal RFP.

C.5. RISK ASSESSMENT

The technical risks associated with the procurement of the telescope subsystem are, for the most part, low because the technology involved is fairly mature. However, there are a few areas where the technical risks can be considered to be the highest. The following areas are considered to have the highest technical risks:

- Tracking smoothness
- Dynamic alignment
- Thermal management
- Wavefront sensing and correction
- Quality assurance

Because of the stringent requirement on tracking smoothness, tracking performance is an area of concern. To meet the tracking requirements, an excellent bearing, encoder, drive, and servo control algorithm must be installed and properly tuned. The risk level can be controlled by proper design reviews with engineers expert in this area. Another area of technical risk is associated with the alignment stability of the primary/secondary mirrors during temperature changes and gravitational load changes. This risk can be minimized through proper structural design and with active control. The technology and know-how to minimize this risk is available; but again, proper attention must be given to the problem to ensure an adequate solution. The third technical risk listed above, thermal management, is largely controlled by proper enclosure design, site orientation, choices of materials, and management of heat sources. In general the sources of problems are fairly well understood and solutions are beginning to emerge. However, this project may not be able to afford some of the more exotic solutions because of budget limitations. Therefore, a careful trade-off is required to determine which approaches offer the most cost effective solutions. The technical risk area associated with adaptive optics should be considered a risk only because of the low maturity level for this type of application which means there are virtually no suppliers of systems or components designed for this application and there is no field history on performance, cost, or reliability. The last area of technical risk associated with quality assurance is not in itself a technical risk, but can increase the level of risk for all performance and operational areas. Because of the number of telescope subsystems involved and the length of time required to complete all of the subsystems, quality assurance is very important in all aspects of the this procurement. Quality assurance will ultimately affect the performance and operational aspects of the subsystems as much as any design. The risks associated with poor quality can be decreased by promoting good working relationships between the CHARA Array team and the contractor, establishing a realistic schedule, establishing well understood requirements, demanding adequate design reviews, demanding adequate in-process and acceptance testing, and proper subsystem management.

The schedule risks associated with the purchase of the telescope subsystem can be minimized by the development of a realistic schedule, adequate management of the project, the selection of a contractor with a mature design, and having adequate and stable capital and personnel resources to complete the project.

The cost risks for this procurement will be minimized by the fixed price contract. However, there can be some risk associated with legal actions associated with breach of contract by the contractor, stop-work orders, dismissal of a contractor and establishment of a new procurement, cost overruns for development of new technologies (e.g. wavefront compensation assembly). Again, the risk associated with these situations can be minimized by proper planning and sound management practices.

C.6. SUMMARY

Development of a comprehensive specification for the telescope subsystems is nearing completion. The specification is based on system requirements and has been developed with input from contractors knowledgeable in this area. The results of an RFI package sent to a number of U.S. and foreign contractors indicate a high probability that the telescope subsystems can be purchased from one of these contractors. Only moderate technical and cost risks are associated with the procurement of the subsystems and low schedule risks have been predicted. Only in one specific area, that of wavefront compensation, is a risk reduction program being recommended.