NGAO Cost Estimation Guidelines

KAON #546

Version 0.5

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Revision Sheet

Revision No.	Date	Revision Description
Rev. 0.1	12/13/07	Initial draft for discussion at NGAO Team Meeting #12; with significant sections borrowed with permission from Jeff Oram's TMT Cost Estimating Plan, TMT.BUS.SPE.05.001.REL02[1]
Rev. 0.2	1/15/08	Simplified several code tables; added discussion of project phases; added overall process flowchart
Rev. 0.3	1/24/08	Filled in several TBD's in preparation for Team Meeting #13; added Junior Engineer position to labor cost schedule
Rev. 0.4	1/28/08	Added clarifications raised and discussed at 1/25/08 process kick off meeting. Added project phase definitions and request for support equipment listing.
Rev. 0.5	1/29/08	Updated Appendix WBS charts.

[1] Jeffrey Oram, TMT Observatory, private conversation 12/12/07.

CONTENTS

1. General information

1.1. Purpose

These Cost Estimation Guidelines contain the cost estimation background and standardization guidelines for the NGAO System Design (SD) Phase Cost Estimation task, SD Phase WBS 4.1.1, including detailed information on the Basis of Estimate (BOE) and cost contingency, as well as the detailed guidelines that have been employed in the generation of the cost estimate.

1.2. Definitions

Backoffice tools	One or more scripts that will be used to extract, collate, and combine BOE inputs for reporting purposes

1.3. Acronyms and Abbreviations

AO	Adaptive optics
BOE	Basis of estimate
CER	Cost estimating relationship
NGAO	Next-Generation Adaptive Optics
PD	Preliminary Design
SD	System Design
SEMP	Systems Engineering Management Plan
WBS	Work breakdown structure

1.4. Points of Contact

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2. Methodology

2.1. Objectives

The primary objective is to develop a comprehensive estimate of the total NGAO project cost, excluding for now back-end instrumentation. This includes the costs for engineering, design, analysis, procurement, fabrication, assembly, inspection, administration, installation, and commissioning of the telescope, instrumentation, and support facilities.

The cost estimates will be prepared by the responsible technical experts who are experienced in the various fields required to design, build, and commission the NGAO system. Vendor quotations, engineering calculations, analogies based on prior telescope programs, and parametric cost estimates will be collected and organized into a Basis of Estimate (BOE). A copy of the BOE for each estimated item will be included as part of the NGAO Cost Book, which will be organized according to the NGAO Work Breakdown Structure (WBS). This Cost Book will furnish NGAO management as well as the reviewing organizations with the data required to substantiate all estimates. The documentation will include the basic configuration information and list all critical assumptions used during the estimating process. The BOE's and resulting Cost Book will be prepared according to the guidelines established in this plan.

Large, complex, and challenging projects entail uncertainty and cost risk. A contingency to cover anticipated costs resulting from this uncertainty will be developed using standardized risk analyses as established in this cost estimating plan. Contingencies will be developed at the same level of the WBS used to prepare the cost estimates.

NGAO costs will be monitored and controlled over the life of the project. The cost estimate will be integrated with the project schedule to establish a time phased budget baseline in a formal project management control system. The control system will compare actual costs with the project's budget baseline and the work accomplished to develop visibility into the project's cost and schedule status during the construction phase. Thus, it is vital that the guidelines established by this plan be strictly followed to facilitate subsequent project monitoring activities and give the Observatory upper management and their Keck partners a high level of confidence that the project is being carefully and professionally managed.

2.2. Process

The NGAO SD Phase System Engineering Management Plan (SEMP) calls for the generation of a system cost estimate, to a level of fidelity appropriate for the system design phase, following completion of the AO System Design work packages (WBS 3.2 and 3.3). The process flow for the NGAO SDR phase cost estimation task (WBS 4.1.2) is shown in Figure 1.

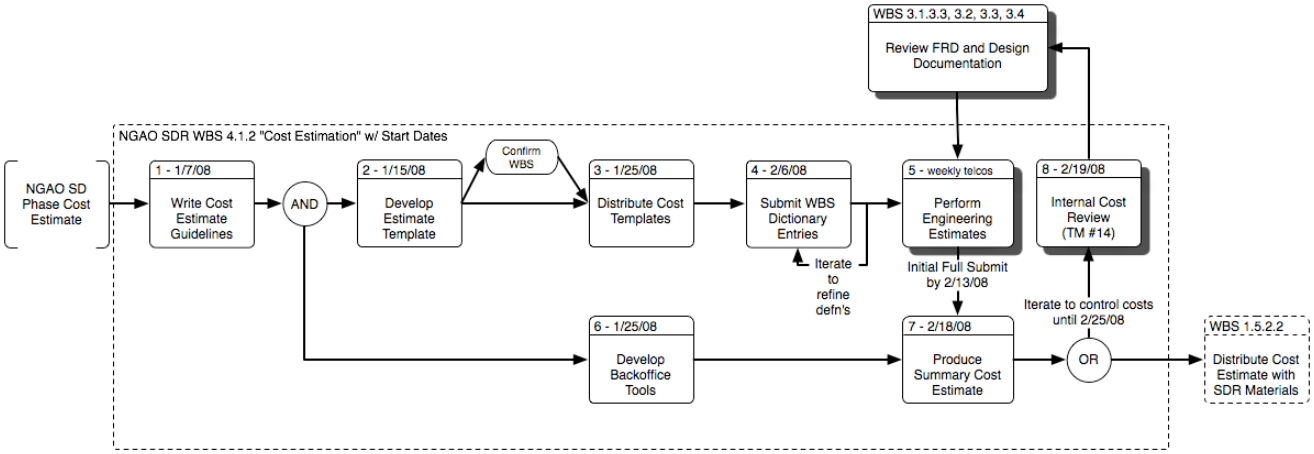

Figure 1. NGAO System Design Phase Cost Estimation WBS 4.1.2 Process Flow. Shadowed processes involve all NGAO team Estimators.

2.3. Basis of Estimate

The cost estimate developed according to this plan shall be a detailed bottom-up estimate performed at the lowest reasonable level within available time. Where strong parametric relationships have been established for specific portions of the estimate, a Cost Estimating Relationship (CER) may be utilized and referenced in the BOE. All estimates will be based on **Base Year (2008) dollars**. A Work Breakdown Structure (WBS) will be used to sum estimates to intermediate and upper levels. Escalation will be applied at the lowest reasonable level to adjust costs to the anticipated Spending Basis where applicable; the Spending Basis estimate will be available in addition to the Base Year estimate.

Cost estimates shall be summarized in an MS Excel, organized to mirror the project WBS. The WBS hierarchy will delineate all subsystems and divide those subsystems into successively lower levels. For each lowest level of the WBS specific design, fabrication, procurement, assembly, quality, test, installation, commissioning, integration, and management activities will be defined. Within each activity, items to be estimated include direct funded staff labor, contract labor, equipment, travel (foreign and domestic), materials and supplies, computer costs, subcontracts, shipping and all overhead costs specific to the labor elements.

The cost estimator shall provide supporting information in the form of a BOE for each activity. The BOE shall contain supporting information substantiating each cost data item including vendor quotations, engineering calculations, parametric cost estimating relationships, graphs, figures, etc. This information shall be provided with the cost estimate to be included in the NGAO Cost Book. This information will be used during internal and external reviews of the NGAO cost estimates.

2.4. Work Breakdown Structure

The Work Breakdown Structure (WBS) is a product-oriented hierarchy that identifies all the elements of the NGAO project and their parent/child relationships. The scope of work for each WBS element will be described thoroughly in the WBS Dictionary. Each lowest-level WBS element shall be estimated independently for each program phase including Preliminary Design, Detailed Design, Construction, and Commissioning. The cost estimate for each activity shall be based on the scope of work defined for the WBS element for each defined program phase.

The WBS and associated WBS Dictionary will be maintained as part of the cost estimating system and placed under configuration control. A portion of the Work Breakdown Structure through all level three items is included in the Appendix; the full NGAO WBS is maintained by NGAO management **(TBD - need to define under document control)**.

2.5. Project Phases

For each BOE, the full cost-to-completion will be subdivided into four project phases:

NGAO Project Phase	Phase Code	Duration[2]
Preliminary Design	PD	18 months
Detailed Design	DD	20 months
Full Scale Development	FSD	24 months
Delivery and Commissioning	DC	18 months[3]

For guidance on the level of maturity of design, we adopt for this costing exercise the Keck Instrument Development Program Definitions of project phases[4] as follows:

Preliminary Design

The preliminary design phase has two primary objectives. The first objective is to deliver documented designs for each system, sub-system and component, hardware or software, of sufficient detail to establish through inspection and analysis the feasibility of the proposed design, and the likelihood that the design will meet the requirements. The second objective is to present the project plan to completion, including a detailed schedule and budget.

The principal activities of the preliminary design phase are design, prototyping, simulation and analysis. The key deliverables are preliminary technical specifications, a preliminary Operations Concept Document, Interface Design document(s), and a Preliminary Design report.

Because of long lead times, orders for custom optical components may need to be placed after a successful preliminary design review. This requires complete, final designs for all of the optical components that are to be ordered and a satisfactory level of design completion for the mechanical components associated with those optics.

Detailed Design

The detailed design phase has two primary objectives. The first objective is to complete the design, fabrication and assembly documentation for the system and all components, hardware or software, and show that the final design complies with all specifications and applicable standards. The second objective is to present the project plan to completion, including a schedule and budget.

The principal activity of the detailed design phase is hardware and software design. The key deliverables are complete, final designs for all hardware components ready for fabrication or procurement release, final functional requirements for all software modules, a final Operations Concept Document, a final technical specification, a Configuration Control Plan, Interface Control Document(s) and a Detailed Design report.

Full Scale Development

The full-scale development phase builds the hardware, codes the software and integrates the complete system and performs laboratory testing culminating in the completion of an acceptance test plan followed by a pre-ship review.

The deliverables for the full-scale development phase an Acceptance Test Plan, a Science Verification Plan, the complete hardware and software system with all as-built documentation, manuals, interface documents, Part I of the Acceptance Test Report and spares.

[2] These durations are tentative for the purpose of the SD Phase cost estimation task and will be updated for future revisions to the project cost estimate.

[3] We expect the majority of labor to be expended in the initial 12 months of the DC phase, but allow for an 18-month phase to fully complete transition to routine science operations.

[4] Adkins, S., "An Overview of the WMKO Development Phases", December 8, 2005.

Delivery and Commissioning

The objective of the delivery and commissioning phase is to install the instrument on one of the Keck telescopes, verify the correct operation of all hardware and software, perform first light observations and gather the data needed to complete part II of the Acceptance Test Plan. At the end of the commissioning process an acceptance review is held to ensure that all of the documentation, spares and procedures are in place to allow the Observatory staff to assume responsibility for operating the instrument during the remaining on-sky testing and the start of shared risk observing.

The deliverables for the delivery and commissioning phase include a report on part II of the Acceptance Test Plan and an Acceptance Review report.

2.6. Costing Methodology

Each WBS Estimator shall provide data for each activity. This data will be entered into an MS Excel template established by Project Management for this purpose. The estimator will provide this data by completing input forms and submitting them to Project Management. The necessary labor resources and non-labor costs for each cost element shall be distributed by project phase (§2.5) and be categorized by labor category (§2.7.1), equipment, travel (§2.7.3), materials and supplies, and subcontracts. This information will enable reports summarizing the cost estimate at various WBS levels.

Each item in the cost estimate shall be tagged with a descriptor that characterizes the method used to derive the estimate. The categories established for this project in decreasing order of general confidence, and the associated code for entry in the Cost Estimating Input Form, include:

Estimating Methodology	Input Code
Direct Historical Data ("done before")	DH
Catalog Prices	CP
Vendor Quotes	VQ
Cost Estimating Relationship	CER
Engineering Estimate	EE

Each methodology is defined in the following fashion:

- Direct Historical Data - The use of costs demonstrated in immediate, applicable history for the same product or service.
- Catalog Prices - A known, advertised price from a potential supplier for a specific product or service.
- Vendor Quote - A quote from a potential supplier within the program estimate. Note: although useful to refining our current cost estimates, a balance must be found that satisfies project needs while not alienating vendors who often commit considerable resources for the generation of detailed price quotes.
- Cost Estimating Relationship – An estimate based on **parametric relationships**, **analogy to another program**, or by **"Rule of Thumb."**
    - Parametric Estimate – A statistical model based on characteristics and costs of multiple previous observations.
    - Estimate by Analogy - Scaling of costs demonstrated in previous observations using subjective or objective factors.
    - Rule of Thumb - General cost relationships demonstrated by informal studies of past programs.
- Engineering Estimate – An estimate based on the judgment of a recognized authority.

2.7. Resource Pricing

Labor, Non-Labor, and Travel costs will be based directly on information provided by the cost estimator. All Labor Resource estimates will be provided **in hours of direct effort** required to complete the work package and/or perform the task; the cost of labor resource estimates will be calculated within the cost estimating system utilizing the hours estimated. Non-Labor expenses such as materials, subcontracts, and non-travel direct costs will be estimated based on the unit cost and number of units required. Travel costs are based on the number of trips, general trip location, and duration of the trip. A rationale must be provided for each resource estimate and included in the estimate BOE.

2.7.1. Labor Resources

Average NGAO labor rates for each labor category will be used when available for pricing direct labor. The labor categories available for use in the estimating process, the associated code for entry in the Cost Estimating Input Form, and comparable Salary Grade are provided in the following tables.

Resource	Input Code	Salary Grade
Technical Functions:		
Post Doc	PostDoc	**A**
Technician	Tech	**A**
Junior Scientist / Engineer	JunSci	**B**
Associate Scientist / Engineer	AssoSci	**C**
Information Tech. Specialist	IT	**C**
Senior Scientist / Engineer	SrSci	**D**
Lead Scientist / Engineer[5]	LdSci	**E**
Business Functions:		
Administrative I	AsstAdmin	**A**
Administrative II	AssoAdmin	**B**
Management Functions:		
Subsystem Manager	SubMgr	**E**
Project Manager	ProjMgr	**E**

All estimates shall be provided in hours of productive effort required to accomplish the task. The rates used to price labor hours will be adjusted to include paid leave such as sick leave, vacations, holidays, etc. These rates will be entered into the cost estimating system NGAO management. For estimating purposes, the typical 2,080 hour working year will be reduced to 1,800 hours to account for the expected annual productive hours. The hourly labor rates will be adjusted such that the 1,800 hours estimated will be priced at a full year of salary. In addition, all fringe benefits and other indirect costs will be included and applied by the cost estimating system utilizing demonstrated and expected burdening factors.

NGAO project blended salary estimates, in $FY08, for each salary grade are as follows and are to be used as a comparative reference:

Grade	Blended Annual Salary ($US\$_{08}$)
A	XX[6],000
B	XX,000
C	XX,000
D	XX,000
E	XX,000

Contract Labor rates will be based on historical rates and/or cost estimates provided by potential contractors, and will be reflected within the total subcontract price estimate. No additional benefits or overhead will be applied to subcontract estimates, as it is assumed that all such benefits are included in the cost of the contract.

2.7.2. Non-Labor Expenses

All non-labor and non-travel expenses that will be directly charged to NGAO must be included as a non-labor expense estimate. This includes, but is not limited to, all subcontracts, materials and equipment, and shipping costs. The estimator will provide the required number of units, including spares and consumable units, and the estimated unit cost for each such item. The cost estimating system will apply any applicable burdens and determine the total cost for each set of non-labor expenses contained in the estimate.

All non-labor estimates will be placed into the appropriate category to identify the type of activity that will take place. The categories, and the associated code for entry in the Cost Estimating Input Form, include:

[5] This designation should be reserved for tasks requiring extraordinary technical expertise (aka “gurus”).

[6] These rates will be determined as part of the processes of summarizing project costs. Upon completion of this costing exercise, this table will be updated to document the assumptions made.

Category	Input Code
Equipment	EQP
Material	MAT
Subcontract	SUB
Shipping	SHIP
Other Direct Cost	ODC

2.7.3. Travel

All travel in support of an activity will be included as part of the input sheet submitted for that item. Travel estimates will be performed by determining the number of trips that will be required based on the general location and duration. Travel destinations, and the associated code for entry in the Cost Estimating Input Form, include:

Destination	Input Code
Intra - California	CALIF
Hawaii - California	HAWAII
International (Origination/Destination unspecific)	INTER
Other locations not included in above list	OTHER

Additionally, the duration of the trip must be included based on the following criteria:

Duration	Input Code
Extended: More than three weeks.	EXT
Long: Greater than one week but less than 3 weeks.	LONG
Mid: Greater than 3 days but less than 1 week.	MID
Short: Three days or under	SHORT

The estimator must determine the number of trips for each applicable destination and duration combination. Standard rates for each such combination will be determined by NGAO Management and applied within the cost estimating system.

Travel applicable to conferences, project-wide reviews, outreach, and funding source meetings will be included as costs in the NGAO Project Management WBS element and **are not to be included** as part of the input sheets submitted for a particular item. Team meetings, conference travel, etc. are to be included in WBS 2.2, Project Management and Meetings.

As a rule, estimators should assume that entire Level 3 WBS elements (e.g. WBS 4.4) will be executed entirely within a single partnership organization. (I&T elements, of course, will require multiple institution participation and are expected to require considerable travel.)

We will include the labor costs for travel itself (e.g. 'sitting on a plane') in the travel section of our cost summarizes (e.g. using the backoffice tools). Estimators should therefore include in their WBS element labor resource estimate only the actual work hour spent at the destination site, and not labor hours while traveling.

2.7.4. Shipping

Shipping for each element to its integration point, assumed to be W. M. Keck Observatory HQ in Kamuela, HI, is to be included with the estimate for that cost element. The cost of shipping integrated elements from WMKO to the summit will be estimated as a cost for the Integration and Test element of the WBS. Include insurance costs for all shipments between California and Hawaii (**TBC**).

2.8. Specific Guidelines

2.8.1. Software Licenses and Computing Resources

Estimators should indicated the level of software license support (Zemax, SolidWorks, etc.) and other NGAO-dedicated computing resources required for each work package in the Misc Comments section of the appropriate BOE. Project Management will assess the overall needs across the project and within each organization as a 'backoffice' activity to appropriately estimate these costs.

2.8.2. Spares

Estimators should not include spare parts costs in their respective cost estimates, but should make note of recommended spares in the Misc. Comments section of each BOE worksheet, **both to protect against damage during development and to ensure continuity of service during operations**. Project management will consider the available budget and importance of various spares purchases (in consultation with respective cost estimators) to develop a project-wide spares plan, which will be reported in WBS 9.2 Operations Maintenance Plan & Spares.

2.8.3. Establishment of Internal Interfaces

WBS 3.6 includes activities for both determining the set of required internal interface control documents and the maintenance of ICD's, once established. Labor resources needed for the definition of internal interfaces, however, should be estimated as part of each work element.

2.8.4. Integration and Testing

Estimators should assume that each subsystem element includes sufficient software development and subsystem I&T such that **the subsystem can be considered as 'proven' input to the next higher level I&T work elements** (e.g. WBS 4.6 or 5.6). In some cases, software needed for low-level testing can be considered discardable, in others it may be more appropriate to develop deliverable control software (e.g. WBS 4.4 or 5.5) as a prerequisite for subsystem testing. Where appropriate, cost estimators should consult with the WBS 4.4. and 5.5 estimators to determine a strategy and document these assumptions under Misc Comments on each BOE.

WBS 8.1, 8.3, 8.4, and 8.5 are assumed to include I&T activities associated with **multiple science instruments**, each. Namely, for this costing exercise, estimators should assume separate activities for the system I&T and testing with a modified OSIRIS instrument, the Keck Interferometer/OHANA, an NIR imager, a visible-light imager, and dIFS (but not a visible light IFU or a new NIR single-object IFU).

2.8.5. Support Equipment

Estimators should include support equipment necessary for work package completion (e.g. vacuum pumps, test light sources, etc.) as required equipment within each WBS element. Project management will review these equipment cost estimates and discuss with estimators opportunities to share costs between work elements. The decision whether to collect support equipment into a separate work package (thus stripping it from individual work elements) will be made as part of the cost estimate backoffice review.

2.9. Risk Analysis and Contingency

Contingency established for the NGAO project shall be based on a standardized risk analysis as described below. The cost estimator is responsible for providing risk factors for each activity. The estimator is responsible for assuring that each and every component has an appropriate and defensible contingency applied. Furthermore, for key system components, Monte Carlo risk simulations will be conducted in addition to the risk analysis described above in order to supplement the risk analysis.

2.9.1. Risk Analysis

A risk analysis schema is used to calculate contingency. The method is based on the estimator's evaluation of the technical, cost, and schedule risk for every activity. Technical, cost, and schedule risk factors are used to enter data into the input forms. Standard ranges for these parameters are 1 to 15 for technical and cost risk and 2 to 8 for schedule risk. For select elements deemed critical by Program Management based on cost and/or risk exposure, an additional quantitative risk analysis particular to that element may be performed.

NGAO cost estimators should refer to the Preliminary Technical Risk Evaluation (KAON #510) in completing their BOE's. Additional risk information is presented in the Appendices of the NGAO System Architecture Definition (KAON #499.)

2.9.2. Contingency Calculation Methodology

Risk Factors are assigned as described in Table 1. For technical risk, the value of 1 implies "normal industry supplied off the shelf items," and 15 is reserved for components significantly "beyond the current state-of-the-art." For cost risk, a value of 1 is used to indicate "vendor quote or catalog price for a specific item," and 15 is used for estimates where no data are available. Schedule risk factors range from 2 to 8.

The technical risk factor is multiplied by the risk percentage, which is categorized in Table 2. The applied risk percentage depends on two factors. The first is whether the risk is associated with technical, cost, or schedule concerns. The second is whether these concerns relate to design, manufacturing, materials cost, or labor rate uncertainties. Acceptable values in the range of 1 percent to 4

percent are defined in Table 2. These percentages are multiplied by the corresponding risk factor to determine the contingency to be applied. The resulting percentages are added together to establish the total contingency for the activity. The minimum contingency percentage using this approach is five percent and the maximum is 98 percent.

There may be special cases where the parameter limitations defined above are not appropriate. Some high-risk elements may deserve contingencies greater than 98 percent. In these cases, at the discretion of the estimator and Project Management, higher values may be used. Justification **must** be provided in the supporting documentation.

Risk Factor	Technical	Cost	Schedule
1	Existing design and off-the-shelf hardware	Off-the-shelf or catalog item	(not used)
2	Minor modifications to an existing design	Vendor quote from established drawings	No schedule impact on any other item
3	Extensive modifications to an existing design	Vendor quote with some design sketches	(not used)
4	New design within established product line	In-house estimate for item within current production line	Delays completion of non-critical path subsystem item
6	New design different from established product line. Existing technology.	In-house estimate for item with minimal company experience but related to existing capabilities	(not used)
8	New design. Requires some R&D development but does not advance the state-of-the-art.	In-house estimate for item with minimal company experience and minimal in-house capability	Delays completion of critical path subsystem item
10	New design. New development of new technology which advances the state-of-the-art.	Top down estimate from analogous programs	(not used)
15	New design way beyond the current state-of-the-art	Engineering judgment	(not used)

Table 1. Contingency Estimation Risk Factors

Category	Condition	Risk Percentage
Technical	Design or manufacturing concerns only	2%
	Design and manufacturing concerns	4%
Cost	Material cost or labor rate concern	1%
	Material and labor rate concern	2%
Schedule		1%

Table 2. Contingency Estimation Risk Percentages

Risk analyses shall be performed at the lowest level of the cost estimate. Results of this analysis will be summed to compute the contingency that will be reported at each level of the WBS.

Though contingencies will be estimated at the same level as the bottom-up cost estimate, during execution of the project contingency will be held at the top level by NGAO management and allocated as needed to address problems and items or activities that have been overlooked during the estimating process. A formal change control process will be used to allocate contingency to specific activities.

2.9.3. Risk Mitigation Activities

Estimators should not include risk mitigation / prototyping costs in their respective cost estimates, but should make note of recommended risk mitigation / prototyping activities in the Misc. Comments section of each BOE worksheet. Project management will consider the available budget and importance of various risk mitigation activities in the PD and DD phases (in consultation with respective cost estimators) to develop a risk mitigation plan.

2.10. Escalation

The NGAO CCE is based on year 2008 dollars. Escalation will be computed using **5% per annum**. Escalation will be applied by NGAO management at the resource level in the cost estimating system by utilizing a particular escalation factor or blend of factors appropriate to the content of work for each item or resource estimated.

Because we are not developing a detailed schedule at this point, all costs, developed by project phase in 2008 dollars, will be escalated to the mid-point of that phase (PD, DD, FSD, and DC).

3. Appendix: NGAO Work Breakdown Structure