



TMT Observatory Corporation

## **TMT Observatory Corporation**

### **Draft Statement of Work for Production of the TMT Primary Mirror Optics**

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**Date Issued: January 30, 2009**

The information contained herein is provided to the recipient for the purpose of preparing a proposal to the Thirty Meter Telescope project. The organization to which this RFP is addressed may utilize the information contained herein only for the above stated purpose and shall not disseminate it to anyone not involved in the preparation of its proposal.

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# 1 Introduction

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## 1.1 Background

This draft Statement of Work (SOW) describes the activities and responsibilities of a Contractor to manufacture, test, and deliver the TMT Primary Mirror (M1) Optics to the Observatory. It is anticipated that the final statement of work that is included in a contract for production of the M1 Optics will contain additional details that will be developed through discussions between TMT and the Contractor.

A description of the M1 Optics and relevant background information are provided in the TMT M1 Overview Document [Ref. 1].

## 1.2 Sections of this Statement of Work

This Statement of Work is split in to two sections:

Section 2 describes the activities and responsibilities of a Contractor to manufacture, assemble and deliver the Segment Support Assemblies (SSAs). The SSAs are the mounts which support the individual segments, and are further described and illustrated in [Ref. 1] and [Ref. 9]. TMT has produced a design for the SSAs, and is in the process of testing prototypes. Design refinement will continue in the near term, ultimately producing a final design. The activities described in Section 2 are envisioned as a “build to print” implementation of that final design.

Section 3 describes the activities and responsibilities of a Contractor to manufacture, test, and deliver the Polished Mirror Assemblies (PMAs). The PMAs are the polished and mounted segments, and are further described and illustrated in [Ref. 1].

The work described in Sections 2 and 3 would preferably be carried out in its entirety by the Contractor. Alternately, the Contractor may elect to carry out only the work described in Section 3. In this case, TMT would be responsible for the manufacture, assembly and delivery of SSAs to the Contractor. The Contractor would be responsible for the manufacture of the segments, integration of the segments to the SSAs, and testing. Regardless of the source of the SSA hardware, the Contractor is not responsible for any performance risk inherent to the design of the SSAs; these risks are born by TMT.

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## 2 Segment Support Assembly Fabrication SOW

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### 2.1 Project Scope

Contractor shall fabricate, assemble and deliver the following items, which are collectively termed the “SSA Hardware,” as follows:

- 492 Subcells + 8 spare Subcells, (the “Subcells”) delivered to TMT
- 574 Polished Mirror Assembly Kits + spare components (the “PMA Kits”), provided by the Contractor to support the PMA production process described in Section 3.

Each Subcell shall consist of the following hardware. Further details are available in the SSA PDR Package [Ref. 9].

- One (1) Fixed Frame Assembly. Note that there are two versions of the Fixed Frame, one used in Sectors A, C and E, and another used in Sectors B, D and F.
- Three (3) Adjustable Alignment Positioners (AAPs)

Each PMA Kit shall consist of the following hardware. Further details are available in the SSA PDR Package [Ref. 9] and the PMA Assembly Drawing [Ref. 6].

- One (1) Central Diaphragm
- Twenty-seven (27) Axial Flexure Assemblies
- One (1) Moving Assembly
- One (1) Tower Assembly
- Three (3) Lock Assemblies
- One (1) Wiring Harness
- Fasteners and shims as specified on the Polished Mirror Assembly Drawing [Ref. 6].

The Moving Assembly, Tower Assembly, Lock Assemblies and Wiring Harness shall be pre-assembled in each delivered PMA Kit.

The Primary Mirror consists of 492 Segments: 6 instances of each of 82 unique Segment Types. The design of the SSAs is tuned to optimally support each of the Segment Types, therefore 82 unique SSA configurations are required. Note that the only unique features in the 82 SSA configurations are the locations of the 12 sets of holes used to locate the whiffletree joints within the Moving Assembly. All other parts are common to the 82 configurations. The whiffletree parts are also identical before the machining of the 12 sets of holes. In the delivery of the 574 PMA Kits, the Contractor shall deliver seven (7) instances of each of the 82 configurations.

TMT shall provide the Contractor with piece-part and assembly drawings for the SSA Hardware.

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## 2.2 Project Phases

The tasks within this section of the SOW fall into four phases:

- Planning: This phase includes project planning, manufacturing engineering, and preparation of assembly facilities.
- Fabrication and Procurement: This phase includes the fabrication or procurement of all SSA components
- Assembly and Test: This phase includes the assembly and testing of the deliverable subassemblies
- SSA Completion: This phase includes the shipment of the Subcells and PMA Kits and facility decommissioning activities.

Note that these phases may overlap. For example, Assembly and Test may begin before all Procurements have been completed.

## 2.3 Sequence of Hardware delivery

TMT plans to install the Subcells at the Observatory over a relatively short period of time. As such, the delivery of all Subcells to the Observatory is required on or before the date given in Section 2.10.3 below.

In Contrast, the PMA Kits will be assembled to segments over a period of several years. As described in Section 2.1, the PMA Kits must be configured to correspond to a given Segment Type. As such, a PMA Kit configured for the proper Segment Type must be available when a segment of the given type is ready for mounting. The fabrication sequence for the Segment Types is detailed below in Section 3.3.

The Contractor shall produce PMA Kits in an order that supports the fabrication sequence detailed in Section 3.3.

## 2.4 Planning Phase

### 2.4.1 Review of Drawings and Data Package

The TMT Project shall provide a data package documenting the SSA design (the "SSA Data Package"), which includes but is not limited to the following:

- Design review packages
- Analysis reports
- Assembly and test procedures used on the prototypes
- Test reports from prototype testing
- CAD models and drawings that define the prototype tooling, assembly fixtures and test fixtures.

The Contractor shall review the SSA Data Package.

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TMT shall provide engineering drawings and 3D CAD models of the SSA Hardware, including piece-part and assembly drawings (the “SSA Engineering Drawings”). These drawings shall have the following attributes:

- Drawings shall be in English
- Drawing units shall be millimeters (mm)
- Drawings shall use third angle projection
- Drawings dimensioning and tolerancing shall conform to drawing standard ASME Y14.5M-1994

The Contractor shall review the drawings, and formulate a Manufacturing Plan (as further described in Section 2.4.2). Contractor shall identify any Design or Drawing Changes required or desired to facilitate the manufacturing process. The recommended Design Changes should not significantly affect the design or performance, nor increase the cost of the hardware. TMT shall incorporate the suggested Design Changes at its sole discretion.

Design Changes may include, but are not limited to, the following:

- Changes to improve manufacturability
- Changes to accommodate alternate manufacturing processes.
- Changes to incorporate tooling, fiducial or reference features that will facilitate subsequent assembly operations

Drawing Changes may include, but are not limited to, the following:

- Drawing Changes to incorporate corrections, clarifications, or Design Changes as described above
- Drawing Changes to incorporate text in languages other than English. Any drawing containing text in a language other than English shall display the English translation in the same location on the drawing.

Contractor shall implement any Drawing Changes. Contractor shall provide TMT with any and all updated drawings for approval by TMT prior to release for production.

#### **2.4.2 SSA Manufacturing Plan**

Contractor shall develop a “SSA Manufacturing Plan” that:

- Defines Contractor’s manufacturing approach for the SSA Hardware
- Defines the procedures that will be used to assemble and test the Subcells and the PMA Kits
- Defines the facilities, fixtures, and instruments that will be required to assemble and test the Subcells and the PMA Kits
- Includes a capacity analysis demonstrating ability of facility to achieve production rates supporting the TMT delivery schedule
- Describes provisions for data management
- Describes plans for maintenance of assembly and test equipment

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- Defines a “SSA Quality Control Plan” that covers every phase of manufacturing. The SSA Quality Control Plan shall contain, but is not limited to, the following:
  - Plans for quality control of procured parts
  - Plans for inspection and verification of piece parts
  - Plans for material verification of adhesive primers
  - Plans for verification of heat treatment and coefficient of thermal expansion (“CTE”) of all Invar-36 components
  - Plans for calibration of assembly and test equipment
  - Plans for verifying and adjusting the mass and center-of-mass for critical whiffletree components and assemblies.
  - Identification of operations to be witnessed by a Quality Control representative
  - Plans for conducting in-process and final inspections, including pass/fail criteria

Contractor shall submit the SSA Manufacturing Plan to TMT. Contractor must receive written approval of the SSA Manufacturing Plan from TMT before beginning the fabrication of SSA Hardware.

Contractor shall present a summary of the SSA Manufacturing Plan, and any Design Changes proposed in order to improve manufacturability, to TMT at a SSA Manufacturing Plan Review Meeting.

Contractor shall use the manufacturing processes described in its SSA Manufacturing Plan for production of all SSA Hardware, in every phase of the Work. If changes in the SSA manufacturing processes are required, Contractor must obtain advance, written authorization from TMT before taking any action on such changes.

### **2.4.3 SSA Risk Management Plan**

The TMT construction schedule requires that all critical systems be delivered to the Observatory on schedule. The Contractor shall devise and implement a SSA Risk Management Plan that identifies the risk areas that could threaten the delivery schedule of the SSA Hardware. Contractor shall conduct an ongoing risk management program that mitigates these risks and actively reduces the TMT project vulnerability to the risks. Risk areas that should be addressed include at a minimum:

- Supply chain problems or delays, including raw material, factory equipment and custom tooling
- Assembly and testing ramp-up (equipment and manpower)
- Prevention, survival and recovery from events such as facility fires or natural disasters.

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The Contractor is not responsible for any performance risk inherent to the design of the SSAs; these risks are born by TMT.

#### **2.4.4 Assembly Facility Preparation**

Contractor shall prepare a facility or facilities to conduct the assembly, inspection and test operations detailed in the SSA Manufacturing Plan. Contractor activities during this phase include, but are not limited to the following:

- Preparing the facility
- Installing and verifying all required fixtures, instruments, and other equipment
- Recruiting and training personnel
- Implementing the data management provisions defined by the SSA Manufacturing Plan

### **2.5 Fabrication and Procurement Phase**

#### **2.5.1 First Article Fabrication**

Contractor shall produce First Articles of all Fabricated Components. Fabricated Components are any components custom made for the SSA application. Procured Components are standard items purchased off-the-shelf. For example, the Fixed Frame is a Fabricated Component. A standard M6 fastener is a Procured Component.

Contractor shall produce sufficient quantities of First Articles to permit the assembly of the Segment Support Assembly First Articles described in 2.6.1. Contractor shall perform full inspection of all First Articles.

Contractor shall describe the inspection, assembly and testing of the First Article Hardware in the SSA First Article Test Reports. Contractor shall obtain TMT's approval of the SSA First Article Test Report before proceeding with Fabricated Component production runs.

#### **2.5.2 Fabrication and Procurement**

Contractor shall fabricate and procure all Fabricated Components and Procured Components. Contractor shall implement Quality Control provisions per the SSA Quality Control Plan.

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## 2.6 Assembly and Test Phase

### 2.6.1 Segment Support Assembly First Articles

Contractor shall produce two (2) Segment Support Assembly First Articles (the "SSA First Articles").

The first unit to be assembled ("SSA First Article-1") shall include the following:

- One (1) Mirror Cell Simulator, providing an interface for the Subcell. (Note: a similar piece of hardware has been built for the TMT prototype program. Its design will be documented in the SSA Data Package)
- One (1) Subcell
- One (1) Polished Mirror Assembly. The Polished Mirror Assembly shall incorporate an Aluminum segment simulator. This segment simulator shall simulate the mass properties and volume of a glass-ceramic segment, and may have an unpolished optical surface.
- A means to measure the axial loads (e.g. a load cell) at each of the 27 attachment points of the Axial Flexure Assemblies

Contractor shall test the SSA First Article-1 to confirm the following

- Form, fit and function of all SSA Hardware
- Assembly Tooling, equipment and procedures
- Inspection and test equipment and procedures
- Warping Harness operation (mechanical performance, not optical verification)
- Distribution of axial loads between the Axial Flexure Assemblies

The second unit to be assembled ("SSA First Article-2") shall include the following:

- One (1) Polished Mirror Assembly. The Polished Mirror Assembly shall incorporate a glass-ceramic segment.

The glass-ceramic segment shall have the following characteristics:

- The optical surface shall have a polished, specular surface suitable for optical testing using an interferometer. Note that it is not required that the Contractor interferometricly test the segment.
- The optical surface shall be spherical, with a radius of curvature of 62.4m (TBC)
- Figure errors on the optical surface shall not exceed 2um peak to valley
- Mechanical dimensions and tolerances shall conform to the M1 Polished Segment Drawing [Ref. 5]

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Contractor shall test the SSA First Article-2 to confirm the following:

- Surface figure of optical surface with the segment zenith-pointing only, as described in the Specification for Finished Primary Mirror Segments [Ref.3]. Contractor may make this measurement optically, or using a profilometer, as agreed by the Contractor and TMT.
- Form, fit and function of all SSA Hardware
- Assembly Tooling, equipment and procedures, including but not limited to bonding procedures
- Inspection and test equipment and procedures
- Warping Harness operation (mechanical performance, not optical verification)

Contractor shall deliver SSA First Article-2 to TMT for further testing and evaluation.

Contractor shall describe the assembly, inspection and testing of each SSA First Article in an SSA First Article Test Report.

## **2.6.2 Production Assembly and Test**

Contractor shall assemble, inspect and test the PMA Kits per the SSA Manufacturing plan. Inspection of the PMA Kits shall include, but is not limited to, the following:

- Dimensional inspection of critical dimensions on piece parts
- Dimensional inspection of critical dimensions on subassemblies
- Verification of material certifications
- Coupon-level CTE testing of Invar 36 material lots
- Visual inspections to confirm workmanship
- Verification of Wiring Harness continuity and pinout
- Verification that the whiffletree components were properly configured to the given Segment Type.

Testing of the PMA Kits shall include, but is not limited to, the following

- Batch verification of any adhesive and adhesive primers
- Operation of the Lock Assemblies
- Demonstration of full range of travel of the Warping Harness Actuators

Results of these inspections and test shall be documented in PMA Kit Inspection Reports. The PMA Kit Inspection Report for any given PMA Kit shall be contained within a single electronic file

Contractor shall assemble and inspect the Subcells per the SSA Manufacturing plan. Inspection of the Subcells shall include, but is not limited to, the following:

- Dimensional inspection of critical dimensions on piece parts

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- Dimensional inspection of the critical dimensions on the Fixed Frame Assemblies
- Verification of material certifications
- Visual inspection to confirm workmanship

Results of these inspections shall be documented in a Subcell Inspection Report. The Subcell Inspection Report shall be contained within a single electronic file.

## 2.7 SSA Completion Phase

### 2.7.1 SSA Hardware and Data Delivery

Contractor shall supply the PMA Kits to the PMA Integration process described in Section 3 as follows:

- 574 PMA Kits + spares as required by the PMA integration process
- Seven (7) PMA Kits shall be provided for each of the 82 Segment Types. Each PMA Kit shall be labeled with the corresponding Segment Type and serialized.

Contractor shall deliver to TMT the PMA Kit Inspection Report for a given PMA Kit within 30 days of the Contractor's Final Inspection of that PMA Kit.

Contractor shall deliver the Subcells to TMT as follows:

- 246 + 4 spare Fixed Frame Assemblies for use in Sectors A, C and E
- 246 + 4 spare Fixed Frame Assemblies for use in Sectors B, D and F
- 1476 + 24 spare Adjustable Alignment Positioners

The Delivery to TMT shall occur at the Contractor's facility. The Contractor shall be responsible for providing shipping container(s) and packing of the subcells in the shipping container(s). TMT shall be responsible for the shipment of the Subcells to the Observatory.

Contractor shall deliver the Subcell Inspection Report to TMT within 30 days of the completion of the Contractor's Final Inspection.

Contractor shall deliver to TMT spare PMA components. Quantities of spare parts shall equal one percent (1%) of the production quantity. For example, the production quantity of Moving Frames is 574, so the quantity of required spares is 6. The production quantity of Mirror Rod Flexures is 15,498, so the quantity of required spares is 155. Spare Whiffletree Triangles shall be supplied without the pivot holes drilled, thereby permitting them to be configured for use with any of the Segment Types.

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## **2.7.2 Assembly and Test Hardware Delivery**

Contractor shall compile a SSA Hardware Equipment Inventory, listing all hardware and software required to assemble and test the Subcells and the PMA Kits. The SSA Hardware Equipment Inventory shall include, but is not limited to, the following:

- Commercial Off the Shelf (“COTS”) tools and equipment used to assemble and test the SSAs
- Custom made tools, fixtures, instruments or equipment used to assemble and/or test the SSA Hardware (“SSA Assembly Tooling”)

After the completion of the 574<sup>th</sup> PMA, as described in Section 3, Contractor shall deliver one complete set of SSA Assembly Tooling. The delivery of the SSA Tooling shall enable TMT to store this equipment for future use in the event that segment(s) must be replaced or reworked. Contractor shall be responsible for packing the SSA Assembly Tooling. TMT shall be responsible for shipping the SSA Assembly Tooling.

## **2.7.3 Inspection and Acceptance**

The requirements of the following Federal Acquisition Regulation (FAR) clauses [Ref. 10] are incorporated in this contract with the exception that all instances of “Government” will be replaced by “TMT”:

- 52.246-1 Contractor Inspection Requirements
- 52.246-2 Inspection of Supplies—Fixed-Price
- 52.246-16 Responsibility for Supplies

## **2.8 Meetings**

Contractor shall hold monthly status meetings with the TMT Project where Contractor shall present and discuss the technical, schedule, and program status of the SSA Fabrication effort with TMT. The monthly progress meeting can be a videoconference or similar. The Contractor shall provide a proposed agenda and a copy of the presentation material prior to each meeting. The Contractor shall also submit to TMT, after each meeting, a Schedule and Meeting Summary Report including schedule status and the tracking of action items.

TMT may elect to locate representative(s) at any Contractor facility during any stage of the Work. Contractor shall provide access to an English-language translator, a work area, telephone, fax and internet access.

Approximately every six months, or at the request of the TMT Project, the Contractor shall participate in a major program review. The purpose of the

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major program review is to allow TMT to review the Contractor's progress, milestones, technical direction, and future plans.

The scope of a major program review may vary over the duration of the TMT Project and may take the form of design reviews, prototype planning or data reviews, production readiness reviews, in-process manufacturing data reporting, and other similar subject matter. The major program reviews will be face-to-face meetings held at TMT's discretion either at the Contractor's facility or a TMT location. TMT may elect to invite third-party reviewers to attend meetings, in which case Contractor shall be given advance notice regarding the attendees.

Contractor shall provide TMT with electronic copies of all presentation materials prior to the major program reviews.

## **2.9 Reports and Data Archiving**

Contractor shall prepare written plans, technical reports, and inspection reports as listed in Section 2.10.2 and described throughout Section 2.

All of these documents and any other relevant information or data shall be archived electronically, and transmitted to TMT.

## **2.10 Schedule**

In order to support the construction schedule, the Contractor shall adhere to the following schedule:

### **2.10.1 Receivables**

TMT furnished information shall be provided to the Contractor according to the following schedule:

<b>Receipt Date</b>	<b>Receivable/Milestone</b>
6/13/2011	SSA Data Package
8/13/2011	SSA Engineering Drawings

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### 2.10.2 Data Deliverables

In order to support the construction schedule, the Contractor shall adhere to the following data delivery schedule:

<b>Delivery Date</b>	<b>Deliverable</b>
Monthly	Schedule and Meeting Summary Report per 2.8
As required	Updated SSA Engineering Drawings per 2.4.1
Month 3*	SSA Manufacturing Plan per 2.4.2
Month 4*	SSA Risk Management Plan per 2.4.3
3/16/2012	SSA First Article-1 Test Report per 2.5.1 and 2.6.1
9/14/2012	SSA First Article-2 Test Report per 2.5.1 and 2.6.1
Contractor Final Inspection + 30 days	Subcell Inspection Report per 2.7.1
Contractor Final Inspection + 30 days	PMA Kit Inspection Report for any given PMA Kit per 2.7.1
12/27/2018	SSA Hardware Equipment Inventory per 2.7.2
* Number of months after contract start.	

### 2.10.3 Hardware Deliverables

In order to support the construction schedule, the Contractor shall adhere to the following hardware delivery schedule:

<b>Delivery Date</b>	<b>Deliverable</b>
1/13/2012	SSA First Article-1 per 2.6.1
7/13/2012	SSA First Article-2 per 2.6.1
1/22/2016	Subcells per 2.7.1
As required by PMA Integration Process	PMA Kits per 2.7.1
12/27/2018	PMA Spare Components per 2.7.1
12/27/2018	SSA Assembly Tooling (one set) per 2.7.2

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## 3 Segment Polishing and PMA Integration SOW

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### 3.1 Project Scope

Contractor shall manufacture and deliver 574 Polished Mirror Assemblies in accordance with the requirements established in the Specification for Finished Primary Mirror Segments [Ref. 3]. The 574 PMAs correspond to seven sets of the 82 unique segment types.

If the Contractor does not undertake the Work described in Section 2 of this SOW, TMT shall provide the contractor with the Qty. 574 PMA Kits described therein. In that case, the Contractor shall be responsible for the assembly and test of the SSA First Article-2, as described in Section 2.6.1.

The PMA production performed by the Contractor shall include the following major operations:

- Procurement of low-expansion glass-ceramic Segment Blanks.
- Production of polished hexagonal segments.
- Precision assembly and mounting of the Segment Supports onto the polished hexagonal segments as described in the Specification for Finished Segments [Ref. 3] and PMA Assembly Drawing [Ref. 6].
  - The mounting of the Support System shall require 27 metal-to-glass bonds to attach the axial supports, in addition to a discontinuous metal-to-glass bond for the lateral support system central diaphragm. All bonds shall be proof loaded to verify workmanship.
  - The assembly of the Segment Support shall require alignment and mechanical assembly as described in the PMA Assembly drawing [Ref. 6].
  - If the contractor does not elect to perform the work described in Section 2, the PMA Kits shall be delivered to the Contractor by TMT. After assembly to the segment, Contractor shall be required to perform a power-on operational test of the warping harness. This test shall confirm that all warping harness actuators are operational and able to actuate through their full range. Contractor shall assume that any failures shall require investigation and rework outside the scope of this SOW.
- Final figuring and full-aperture interferometric testing of the finished segment on its support system, while the segment is zenith-pointing and at the mean observing temperature as described in the Specification for Finished Segments [Ref. 3]. Note: The Contractor is not responsible for the performance of the SSA at orientations away from the zenith.

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### 3.2 Project Phases

The tasks within this section of the SOW fall into three phases:

- Planning:
  - This phase includes project planning, manufacturing engineering required for PMA fabrication.
- Production:
  - Initial Deliveries:
    - This phase includes the production and delivery of a PMA First Article (the 1<sup>st</sup> PMA), and the production and delivery of the 2<sup>nd</sup> through 12<sup>th</sup> PMAs.
  - Early Deliveries:
    - This phase includes the production and delivery of the 13<sup>th</sup> through the 120<sup>th</sup> PMAs
  - Final Deliveries:
    - This Phase includes the completion of all PMAs required to fully populate the M1: The 121<sup>st</sup> through the 492<sup>nd</sup> .
  - Spare Segment Deliveries:
    - This Phase includes the completion of all PMAs: The 493<sup>rd</sup> through the 574<sup>th</sup>.
- Completion:
  - The period of time after delivery of the final PMA, including:
    - Decommissioning
    - Storage

### 3.3 Sequence of PMA delivery

TMT shall install completed PMAs in the M1 array in the following sequence:

- Install a contiguous cluster of inner segments (Type  $\leq 44$ )
- Building off the initial cluster, populate the (value TBD) innermost rings of the M1 in all Sectors. (Nomenclature: Segments Types 1 and 2 are in the first ring, 3-5 are in the second ring; 6-9 are in the third ring, etc.)
- Working from the inside diameter outward, populate the remainder of the M1 array
- Begin steady-state segment exchange using the 7<sup>th</sup> set of PMAs

As such, inner segments are required before outer segments, and 6 sets of 82 segments (one of each Segment Type) are required before the 7<sup>th</sup> set. However, it is acknowledged that there may be cost benefits to altering the delivery sequence, e.g. to permit testing all 7 PMAs of any given Segment Type at once, or to intersperse the fabrication of highly aspheric outer segments with mildly aspheric inner segments.

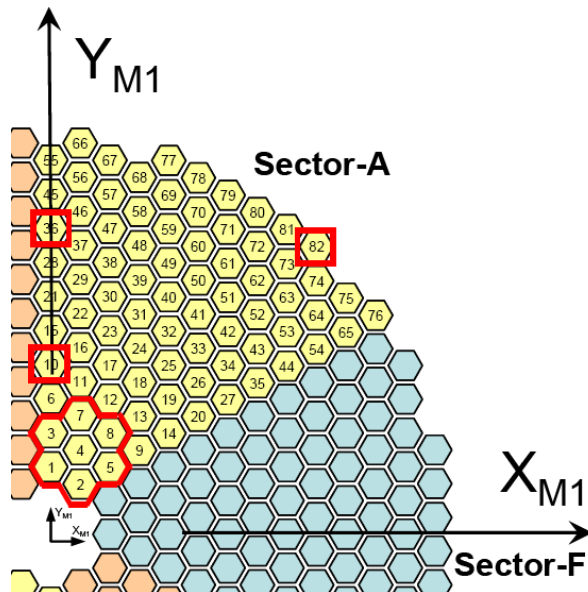
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A baseline delivery sequence is given below. Contractor shall provide feedback on this delivery sequence, and suggest opportunities for process improvement.

**Initial Deliveries (Segments 1-12)**

During the production phase leading up to the Initial Deliveries of segments, the Contractor shall develop the equipment and processes of segment fabrication. Contractor shall fabricate both inner (less challenging) and outer (more challenging) segments. In this phase the Contractor shall fabricate the segments listed below, and shown in Figure 1.

- Type 1 – 5: Qty. 1 each
- Type 7 – 8: Qty. 1 each
- Type 10: Qty. 1
- Type 36: Qty. 2
- Type 82: Qty. 2 (the most aspheric TMT segment type)



**Figure 1: Initial Delivery Segments**

**Early Deliveries (Segments 13-120)**

In this phase the Contractor shall deliver Qty. 108 segments, of Segment Types to be defined by TMT. (Segments fabricated in this phase will be of Type  $\leq 44$ )

**Final Deliveries (Segments 121-492)**

In this phase the Contractor shall deliver the Qty. 372 segments required to fully populate the M1 Array.

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### Spare Segment Deliveries (Segments 493-574)

In the Spare Segment Delivery Phase, Contractor shall deliver the seventh set of segments:

Type 1 – Type 82: Qty. 1 each

### Production Summary:

SEGMENT TYPE	SEGMENTS PRODUCED IN EACH PHASE						
	QUANTITIES GIVEN ARE PER SEGMENT TYPE						
	Initial Deliveries	Early Deliveries	Cumulative Total (initial+early deliveries)	Final Deliveries	Cumulative Total (initial+early+final deliveries)	Spare Segment Deliveries	Total Production TOTAL
1 to 5	1	TBD	TBD	TBD	6	1	7
6	-	TBD	TBD	TBD	6	1	7
7 to 8	1	TBD	TBD	TBD	6	1	7
9	-	TBD	TBD	TBD	6	1	7
10	1	TBD	TBD	TBD	6	1	7
11 to 35	-	TBD	TBD	TBD	6	1	7
36	2	TBD	TBD	TBD	6	1	7
37 to 44	-	TBD	TBD	TBD	6	1	7
45 to 81	-	-	-	6	6	1	7
82	2	-	2	4	6	1	7
<b>Total Segments Produced</b>	<b>12</b>	<b>108</b>	<b>120</b>	<b>372</b>	<b>492</b>	<b>82</b>	<b>574</b>

## 3.4 Planning Phase

### 3.4.1 Confirmation of Segment Calculations

Contractor shall perform calculations to confirm the following key parameters of each of the 82 Segment Types:

- Optical surface prescription
- Hexagonal Outline (Segmentation)
- Mass properties

Contractor shall prepare a “Segmentation Calculation Report” summarizing the methodology and results of the calculations.

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### 3.4.2 PMA Manufacturing Plan

Contractor shall develop a “PMA Manufacturing Plan” that:

- Defines Contractor’s manufacturing approach for the PMAs
- Defines the procedures that will be used to assemble the components of the PMA
- Describes the facilities, machinery, fixturing and tooling that will be required to manufacture and test the PMAs
- Includes a capacity analysis demonstrating ability of facility to achieve Production rates supporting the TMT delivery schedule
- Includes a set of six Production Milestones that can be used to measure Contractor’s progress throughout the facilitization and production phases
- Describes provisions for data management
- Describes plans for maintenance of manufacturing and test equipment
- Defines a “PMA Quality Control Plan” that covers every phase of manufacturing. The PMA Quality Control Plan shall contain, but is not limited to, the following:
  - Plans for calibration of manufacturing and test equipment
  - Plans for material verification of Contractor-furnished materials (e.g. adhesives, primers)
  - Plans for workmanship verification of adhesive bonds, including proof loading of each metal-to-glass bond.
  - Identification of operations to be witnessed by a Quality Control representative
  - Plans for conducting in-process and final inspections, including pass/fail criteria

Contractor shall submit the PMA Manufacturing Plan to TMT. Contractor must receive written approval of the PMA Manufacturing Plan from TMT prior to commencing with facilitization.

Contractor shall identify any design accommodations (e.g. tooling interface locations, fiducials) required or desired to facilitate the manufacturing process. The recommended accommodations should not significantly affect the design or performance, nor increase the cost of the hardware. TMT shall incorporate the suggested accommodations at its sole discretion.

Contractor shall present a summary of the PMA Manufacturing Plan, and any design changes proposed in order to improve manufacturability, to TMT at a PMA Manufacturing Plan Review Meeting.

Contractor shall use the manufacturing processes described in its PMA Manufacturing Plan for production of all PMAs, in every phase of the Work. If changes in the manufacturing processes are required, Contractor must obtain

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advance, written authorization from TMT before taking any action on such changes.

Contractor shall report progress against the six Production Milestones such that the Contractor and TMT can measure progress.

### **3.4.3 PMA Risk Management Plan**

The TMT construction schedule requires that all critical systems be delivered to the Observatory on schedule, and with the required performance. The Contractor shall devise and implement a PMA Risk Management Plan that identifies the risk areas that could threaten the performance or delivery schedule of the PMAs. Contractor shall conduct an ongoing risk management program that mitigates these risks and actively reduces the TMT project vulnerability to the risks. Risk areas that should be addressed include at a minimum:

- Polishing process development
- Optical metrology facility design, manufacture and performance
- Supply chain problems or delays, including raw material, factory equipment and custom tooling
- Production capacity ramp-up (equipment and manpower)
- Prevention, survival and recovery from events such as facility fires or natural disasters.

### **3.4.4 Optical Metrology System**

Contractor shall develop plans for the design, construction, and commissioning of an Optical Metrology System capable of measuring all finished TMT mirror segments as required by the Specification for Finished Segments [Ref. 3].

The Optical Metrology System shall consist of:

- The instrument(s) required to measure the segment across the full range of spatial frequencies defined in the Specification
- An independent instrument or method to verify the segment figure at low spatial frequencies.

Contractor shall prepare an Optical Metrology System Design Report that presents the optical design of the Optical Metrology System, along with simulations and a detailed error analysis that demonstrate that its performance will meet the requirements, for approval by TMT. Contractor shall obtain TMT approval before fabricating the Optical Metrology System.

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## 3.5 Production Phase

### 3.5.1 Procurement of Segment Blanks

Contractor shall procure Qty. 574 + TBD spare Segment Blanks. Segment Blanks shall conform to the Specification for Primary Mirror Segment Blanks [Ref. 4].

Contractor shall provide a Segment Blank Inspection Report for each Segment Blank, demonstrating that the Segment Blank meets the requirements of [Ref. 4]. The Segment Blank Inspection Report shall be provided in a single electronic file (per Segment Blank). The Segment Blank Inspection Report for any given Segment Blank shall be delivered to TMT within 30 days of the Contractor's acceptance of the Segment Blank from a glass supplier. Contractor shall document the serial number of the Segment Blank incorporated in to each PMA.

### 3.5.2 Initial Deliveries Phase

#### 3.5.2.1 PMA First Article production

Contractor shall produce a PMA First Article, of Segment Type TBD. This PMA First Article shall be fully inspected to ensure that it meets the requirements of the Specification for Finished Segments [Ref. 3], and the applicable requirements from the TMT M1 Polished Segment Drawing [Ref. 5] and TMT M1 Polished Mirror Assembly Drawing, [Ref. 6].

In addition to the requirements of [Ref. 3, 5 & 6], Contractor shall perform the following full-aperture optical measurements of the PMA First Article:

- Surface figure of the segment, Zenith pointing (segment local zenith angle  $\zeta_{\text{seg}}=0$ ), at room temperature (20°C). (note that [Ref. 3] requires testing of the segment at observing temperature)
- Warping harness influence functions
- Warping harness application of 2<sup>nd</sup> and 3<sup>rd</sup> order Zernike Shapes of amplitude TBD

TMT personnel shall observe the testing and shall be provided with electronic copies of all test data. The results of the tests shall be documented in a PMA First Article Test Report. If the performance of the PMA does not meet the TMT requirements, TMT may, at its sole discretion, elect to: (1) adjust the requirements to accept the measured performance of the PMA; or (2) change the manufacturing process to ensure the requirements will be met.

Contractor shall not proceed with manufacturing until TMT approves the results of the PMA First Article Test and any subsequent revisions to the PMA Manufacturing Plan.

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### **3.5.2.2 Delivery of the 2<sup>nd</sup> through the 12<sup>th</sup> PMA**

Contractor shall deliver Qty. 11 PMAs, of the types specified in section 3.3. All PMAs shall be fully inspected to ensure they meet the requirements of [Ref. 3, 5 & 6].

Each PMA shall be documented by a PMA Inspection Report, as described in [Ref. 3].

### **3.5.3 Early Deliveries Phase**

#### **3.5.3.1 Delivery of the 13<sup>th</sup> through the 120<sup>th</sup> PMA**

Contractor shall deliver Qty. 108 PMAs, of the types specified in section 3.3. All PMAs shall be fully inspected to ensure they meet the requirements of [Ref. 3, 5 & 6].

Each PMA shall be documented by a PMA Inspection Report, as described in [Ref. 3].

### **3.5.4 Final Deliveries Phase**

#### **3.5.4.1 Delivery of the 121<sup>st</sup> through the 492<sup>nd</sup> PMA**

Contractor shall deliver Qty. 372 PMAs, of the types specified in section 3.3. All PMAs shall be fully inspected to ensure they meet the requirements of [Ref. 3, 5 & 6].

Each PMA shall be documented by a PMA Inspection Report, as described in [Ref. 3].

### **3.5.5 Spare Segment Deliveries Phase**

#### **3.5.5.1 Delivery of the 493<sup>rd</sup> through the 574<sup>th</sup> PMA**

Contractor shall deliver Qty. 82 PMAs, of the types specified in section 3.3. All PMAs shall be fully inspected to ensure they meet the requirements of [Ref. 3, 5 & 6].

Each PMA shall be documented by a PMA Inspection Report, as described in [Ref. 3].

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## 3.6 Completion Phase

### 3.6.1 Facility Decommissioning

Contractor shall provide TMT with a contract option to procure PMAs (“PMA Contract Option”) in addition to the 574 that will be fabricated in Production. The PMA Contract Option shall commence once the 574<sup>th</sup> production segment completes all phases of the manufacturing process and shall have a term of three (3) years. The purpose of this contract option is to allow TMT to replace segments that are damaged during shipping or initial installation in the telescope. If exercised, it is likely that only a few segments would be produced under this contract option. As such, the Contractor is not required to maintain full production capacity during the three year term.

Contractor shall compile a TMT Equipment Inventory, listing all hardware and software required to fabricate, assemble and test PMAs. The TMT Equipment Inventory shall include, but is not limited to, the following:

**TMT-Unique Fabrication Equipment:** TMT-Unique Fabrication Equipment includes process equipment purchased with TMT funds or developed for the specific purpose of fabricating the TMT PMAs. Such hardware includes, but is not limited to the following: Polishing machine(s), polishing fixture(s), control hardware and software developed for, and used by the TMT-Unique Fabrication equipment.

**Critical Metrology Hardware:** Critical Metrology Hardware is defined as hardware that is

- Custom-made or modified for the specific purpose of measuring TMT segments
- Not widely commercially available
- Not integral to the structure of a facility

For example Computer Generated Holograms, transmissive test elements, custom interferometers, and mounts/fixtures for the same would be Critical Metrology Hardware. A refrigerated room within a building would not be Critical Metrology Hardware.

**PMA Assembly Tooling:** PMA Assembly Tooling includes all fixtures and jigs required to assemble or rework PMAs.

At the term of the PMA Contract Option, Contractor shall deliver Critical Metrology Hardware to TMT. Contractor shall be responsible for packing the Critical Metrology Hardware. TMT shall be responsible for shipping the Critical Metrology Hardware.

At the term of the PMA Contract Option, Contractor shall deliver to TMT one complete set of PMA Assembly Tooling. The delivery of PMA Assembly

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Tooling shall enable TMT to repair or rebuild segments in the future if necessary. Contractor shall be responsible for packing the PMA Assembly Tooling. TMT shall be responsible for shipping the PMA Assembly Tooling.

### **3.6.2 Inspection and Acceptance**

Completed PMAs and the associated Inspection Reports, shall be presented to TMT for inspection and acceptance at the Contractor's facility within 30 days of the Contractor's Final Inspection.

The requirements of the following Federal Acquisition Regulation (FAR) clauses [Ref. 10] are incorporated in this contract with the exception that all instances of "Government" will be replaced by "TMT":

- 52.246-1 Contractor Inspection Requirements
- 52.246-2 Inspection of Supplies—Fixed-Price
- 52.246-16 Responsibility for Supplies

Contractor shall store completed PMAs as described in Section 3.6.3, or pack completed PMAs accepted by TMT in Shipping Containers provided by TMT. TMT shall instruct the Contractor whether to store or pack any given PMA at the time of acceptance.

Contractor shall assume that the TMT-provided Shipping Containers are not available for the long-term storage of PMAs described in section 3.6.3.

TMT shall be responsible for the shipping of the Shipping Containers from the Contractor's facility.

### **3.6.3 Storage of PMAs**

After PMAs are delivered to TMT at the Contractor's facility, Contractor shall provide a safe, secure, environmentally controlled warehouse facility for use in storing the TMT segments until such time as TMT ships the PMAs to the Observatory or other destination. During the period of time that the PMAs are being stored at the Contractor's facility, Contractor shall provide insurance against loss or damage for the full replacement value of the PMAs. Contractor shall prepare and provide the storage capacity required to accommodate the production rates and delivery schedule. TMT estimates that the Contractor may need to store up to 350 PMAs at said facility; however this depends on the Contractor's production rates. The storage facility shall be available to receive the First Article PMA, and subsequent PMAs as they are produced, and shall be provided for a period of up to 1 year beyond the completion of the 574<sup>th</sup> segment. .

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At the request of TMT, Contractor shall remove PMAs from temporary storage and prepare them for shipment in TMT provided Shipping Containers.

### **3.7 Meetings**

Contractor shall hold monthly status meetings with the TMT Project where Contractor shall present and discuss the technical, schedule, and program status of the Segment Polishing and PMA Integration effort with TMT. The monthly progress meeting can be a videoconference or similar. The Contractor shall provide a proposed agenda and a copy of the presentation material prior to each meeting. The Contractor shall also submit to TMT, after each meeting, a Schedule and Meeting Summary Report including schedule status and the tracking of action items.

TMT may elect to locate representative(s) at any Contractor facility during any stage of the Work. Contractor shall provide access to an English-language translator, work area, telephone, fax and internet access.

Approximately every six months, or at the request of the TMT Project, the Contractor shall participate in a major program review. The purpose of the major program review is to allow TMT to review the Contractor's progress, milestones, technical direction, and future plans.

The scope of a major program review may vary over the duration of the TMT Project and may take the form of design reviews, prototype planning or data reviews, production readiness reviews, in-process manufacturing data reporting, and other similar subject matter. The major program reviews will be face-to-face meetings held at TMT's discretion either at the Contractor's facility or a TMT location. TMT may elect to invite third-party reviewers to attend meetings, in which case Contractor shall be given advance notice regarding the attendees.

Contractor shall provide TMT with electronic copies of all presentation materials prior to the major program reviews.

### **3.8 Reports and Data Archiving**

Contractor shall prepare written plans, technical reports, and inspection reports as listed in section 3.9.2 and described throughout section 3

All of these documents and any other relevant information or data shall be archived electronically, and transmitted to TMT.

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### 3.9 Schedule

In order to support the construction schedule, the Contractor shall adhere to the following delivery schedule:

#### 3.9.1 Receivables

TMT furnished hardware shall be provided to the Contractor according to the following schedule:

<b>Receipt Date ARO</b>	<b>Receivable/Miles tone</b>	<b>Quantity</b>
7/2/2012	PMA Kits available for Initial Delivery Phase Segments (if provided by TMT)	12
As required by Contractor. No earlier than 7/1/2013. Deliveries over 1 yr. period	Remainder of PMA Kits available (if provided by TMT)	562 + TBD Spares
As required to support TMT shipping schedule (TBD)	Shipping Containers available	TBD, as required by phasing of shipping plans

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### 3.9.2 Data Deliverables

In order to support the construction schedule, the Contractor shall adhere to the following data delivery schedule:

<b>Delivery Date</b>	<b>Deliverable</b>
Monthly	Schedule and Meeting Summary Report per 3.7
Month 2*	Segmentation Calculation Report per 3.4.1
Month 4*	PMA Manufacturing Plan per 3.4.2
Month 5*	PMA Risk Management Plan per 3.4.3
Month 6*	Optical Metrology System Design Report per 3.4.4
Contractor's Acceptance from Glass Supplier +30 Days	Segment Blank Inspection Report for any given Segment Blank per 3.5.1
7/29/2013	PMA First Article Test Report per 3.5.1
As Required	Production Milestone reports (6)
Contractor's Final Inspection + 30 days	Final Inspection report for any given PMA per 3.6.2
12/27/2018	TMT Equipment Inventory per 3.6.1
* Number of months after contract award	

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### 3.9.3 Hardware Deliverables

In order to support the construction schedule, the Contractor shall adhere to the following hardware delivery schedule:

<b>Delivery Date</b>	<b>Deliverable</b>
5/29/2013	PMA First Article complete and ready for first article inspection
11/29/2013	Initial Deliveries Complete: 2 <sup>nd</sup> – 12 <sup>th</sup> PMA delivered
8/31/2016	Early Deliveries Complete: 13 <sup>th</sup> -120 <sup>th</sup> PMA delivered
from 9/30/2016 to 10/31/2017*	Final Deliveries Complete: 121 <sup>st</sup> -492 <sup>nd</sup> PMA delivered and shipped, enabling full population of the M1.
10/31/2018	Spare Segment Delivery Complete: 493 <sup>rd</sup> -574 <sup>th</sup> PMA delivered and shipped
10/31/2021	Critical Metrology Hardware and PMA Assembly Tooling delivered per 3.6
*Segments 121 to 492 shall be delivered at a constant rate (segments per week) over the specified period.	

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## 4 References

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1. **TMT M1 Overview Document: TMT.OPT.TEC.09.003.REL01**  
File: M1 Segment Background.doc
2. **TMT Segmentation Database: TMT.OPT.TEC.07.044**  
File: TMT M1 Segmentation Database REL02.txt
3. **Specification for Finished Primary Mirror Segments: TMT.OPT.SPE.07.002**  
File: TMT OPT SPE 07 002 CCR03 Specification for Finished Primary Mirror Segments – Final.pdf
4. **Specification for Primary Mirror Segment Blanks: TMT.OPT.SPE.07.001**  
File: TMT OPT SPE 07 001 CCR06 – Specification for Primary Mirror Segment Blanks.pdf
5. **TMT M1 Polished Segment Drawing: 280-TMT-01-01000**  
File: 280-TMT-01-01000\_C\_Segment.pdf
6. **TMT M1 PMA Assembly Drawing: 280-TMT-01-11000**  
File: 280-TMT-01-11000\_C\_PMA.pdf
7. **TMT PMA Assembly Process: TMT.OPT.TEC.07.005**  
File: TMT OPT TEC 07 005 REL01 – PMA Assembly Process.pdf
8. **Subsystem Requirements Document for the M1 Optics System: TMT.OPT.DRD.07.007.REL01**  
File: M1S DRD TMT OPT DRD 07 007 REL01.pdf
9. **SSA PDR Volumes 1-7 : TMT.OPT.PRE.07.056-63**  
File: HPS-280001-0105 - Volume-1 (EW,TMT M1 SSA PDR - OVERVIEW).ppt  
File: HPS-280001-0105 - Volume-2 (EW,TMT M1 SSA PDR - SYSTEM-LEVEL CALCULATIONS).ppt  
File: HPS-280001-0105 - Volume-3 (VS,TMT M1 SSA PDR - SYSTEM-LEVEL FEA).ppt  
File: HPS-280001-0105 - Volume-4 (EW TMT M1 SSA PDR - WARPING HARNESS).ppt  
File: HPS-280001-0105 - Volume-5 (EW TMT M1 SSA PDR - FLEXURES).ppt  
File: HPS-280001-0105 - Volume-6 (EW,TMT M1 SSA PDR - HANDLING & INTEGRATION).ppt  
File: HPS-280001-0105 - Volume-7 (EW,TMT M1 SSA PDR - SUMMARY & FUTURE PLANS ).ppt
10. **Federal Acquisition Regulation**  
<http://www.acquisition.gov/far/current/pdf/FAR.pdf>

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## 5 Abbreviations and Acronyms

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3D: Three Dimensional  
AAP: Adjustable Alignment Positioner  
ARO: At Receipt of Order  
ASME: American Society of Mechanical Engineers  
CAD: Computer Aided Design  
COTS: Commercial Off The Shelf  
CTE: Coefficient of Thermal Expansion  
e.g. exempli gratia (for example)  
FAR: Federal Acquisition Regulation  
ID: Inner Diameter  
M1: Primary Mirror  
N/A: Not Applicable  
OD: Outer Diameter  
PDR: Preliminary Design Review  
PMA: Polished Mirror Assembly  
Qty. Quantity  
Ref. Reference  
SOW: Statement of Work  
SSA: Segment Support Assembly  
TBC: To Be Confirmed  
TBD: To Be Determined  
TMT: Thirty Meter Telescope  
Yr. Year

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