THIRTY METER TELESCOPE

DRAFT DESIGN REQUIREMENTS DOCUMENT

FOR

PRIMARY MIRROR COATING PLANT

TMT.OPT.DRD.09.005.DRF01

September 18, 2009

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1. INTRODUCTION

1.1 INTRODUCTION

This design requirements document (DRD) contains requirements for the optical coating plant that will deposit coatings on the 492 primary mirror (M1) segments of the Thirty Meter Telescope (TMT), which is called the "M1 Coating Plant". The requirements for the coatings that are to be deposited are described in the reference document **TMT DRD for Telescope Optical Coatings** (RD2). A portion of RD2 is provided within this document in Appendix II.

This document captures requirements specified in the top level requirements documents, Observatory Architecture Document (OAD), Observatory Requirements Document (ORD), Operations Concept Document (OCD), and system engineering error budgets and provides flow down and interpretation at the level of the M1 optical coating plant. Also included are requirements that originate at the level of this document.

Where the requirements from any applicable or reference documents such as AD1, AD2, AD3, or RD1) are listed herein, they retain their original requirement numbering configuration and are duplicated here verbatim. Specific requirements that originate within this document are assigned requirement numbers within this document.

1.2 PURPOSE

This document is intended to describe requirements for the coating plant that will be used to apply optical coatings to the telescope M1 segments at first light; and additionally, to describe requirements for feasible future upgrades to the coating plant that would enable the application of enhanced coatings that would meet desired science goals.

The document will guide the design and verification of the coating plant used to apply first light optical coatings for the M1 segments during the design and construction phase of the TMT Observatory. During this process, attention to requirements for future upgraded coatings will ensure that the future upgrade will be feasible.

1.3 SCOPE

This document describes the constraints and functional performance requirements of the M1 Coating Plant, which is a major portion of the M1 Coating Equipment work breakdown structure (WBS) element, TMT.TEL.OPT.COAT.M1. The position of this element in the WBS is illustrated in Figure 1.

Included in this document are the requirements for the optical coating plant that will apply coatings to the M1 segments. The coating plant includes the coating chamber assembly with a segment carrier system, partitions as required between zones, ports as needed for vacuum control and source supply; a load-lock entry into the chamber; the vacuum control system including pumps, valves and sensors; the source supply system including reaction materials, energizing method, carrier gases, cabinets and control valves; heaters and cooling systems as required; source supply control hardware such as Mass Flow Controllers, valves and sensors; control electronics; and control software with a user-friendly interface that provides both local control and remote access. An interlocked safety system with Emergency Off Switch, sensors, venting and safe shutdown controls that engage during power loss conditions or hardware failure conditions shall also be implemented to meet safety regulations that apply on Mauna Kea.

Requirements for the coating itself are detailed in RD2, TMT DRD for Telescope Optical Coatings. For coating specification details, RD2 will take precedence.

Not included are requirements for the coating plant that will apply coatings to the telescope secondary or tertiary mirrors or the instrument optical surfaces which are specified in a separate requirements documents.

Not included are all handling equipment required to safely transport, process, store and transfer the segments as they traverse back and forth from their mounting locations on the telescope to storage, to the laboratory where the previous coating will be removed and to the coating plant where the back-shell will be attached and the assembly will be loaded into the coating plant.

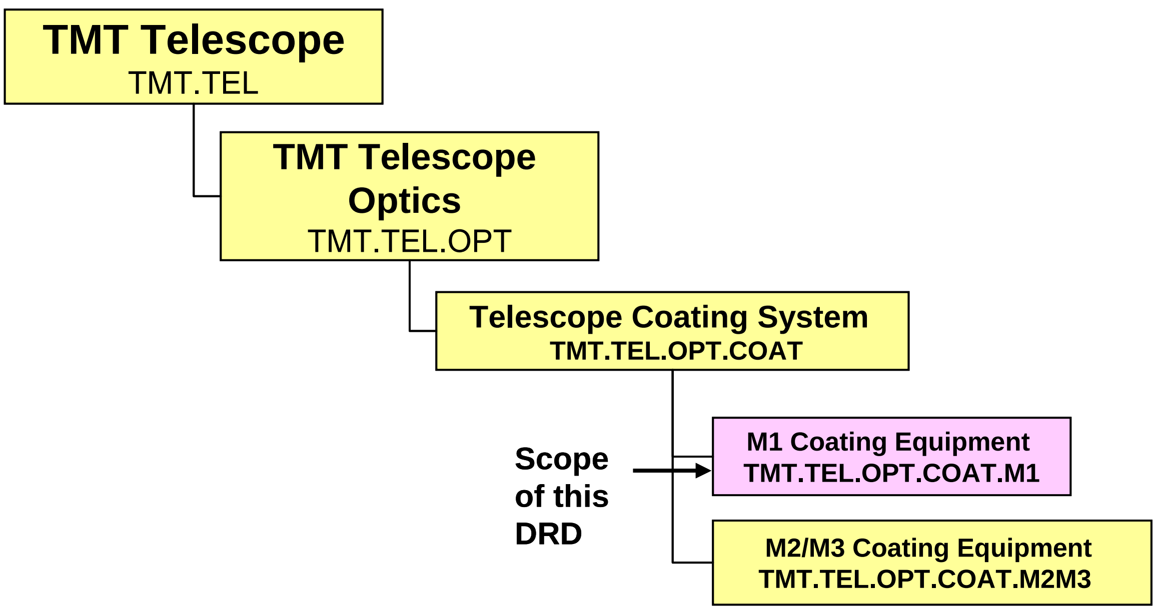

Figure 1. Work Breakdown Structure Element Covered by This Requirements Document

1.4 APPLICABLE DOCUMENTS

Applicable documents are containing information that shall be applied in the current document. Examples are higher level requirements documents, standards, rules and regulations. Documents should be hyperlinked as shown below.

AD1 Operations Concept Document (OCD), (TMT.OPS.MGT.07)

AD2 Observatory Requirements Document, (TMT.SEN.DRD.05)

AD3 Observatory Architecture Document, (TMT.SEN.DRD.05)

1.5 REFERENCE DOCUMENTS

RD1 M1 Optics System Requirements (TMT.OPT.DRD.07.001)

RD2 DRD for Telescope Optical Coatings (TMT.OPT.DRD.09.003)

RD3 Ritchey-Chrétien Baseline Design (TMT.SEN.SPE.06.001)

RD4 TMT Coating System Requirements (TMT.OPT.SPE.06.003)

RD5 Baseline Optical Design of the Thirty Meter Telescope (TMT.SEN.TEC.05.002)

RD6 Interface Control Document, M1 Segment to Coating Plant

RD7 Interface Control Document, TMT Observatory Facility and M1 Segment Coating Plant

RD8 Coating the 8-m Gemini telescopes with protected silver (TMT.OPT.JOU.0.005)

RD9 TMT Polished Mirror Assembly Drawing (TMT.OPT.DWG.07.002)

RD10 Coating Considerations White Paper (TMT.OPT.TEC.08.215)

RD11 TMT Power Usage and Heat Dissipation Budgets (TMT.SEN.TEC.08.054)

RD12 TMT M1 Segmentation Database (TMT.OPT.TEC.07.044)

RD13 TMT M1 Polished Segment Drawing (TMT.OPT.DWG.07.001)

1.6 CHANGE RECORD

Revision	Date	Section	Modifications
DRF01	09/01/2009	All	Initial draft

1.7 ABBREVIATIONS

Ag – Silver

AIV – Alignment, Integration and Verification

EMI – Electromagnetic Interference

COAT – Optical Coating System

Cr – Chromium

Gd - Gadolinium

Hf – Hafnium

M1 – Telescope Primary Mirror

M2 – Telescope Secondary Mirror

M3 – Telescope Tertiary Mirror

MFC – Mass Flow Controller

MSA – Mounted Segment Assembly

N – Nitrogen

Nb – Niobium

Ni – Nickel

Ti - Titanium

OAD – Observatory Architecture Document

ORD – Observatory Requirements Document

OCD – Operations Concept Document

REQ – Requirements

Sc – Scandium

Si – Silicon

SPR – Surface Plasmon Resonance

SSA – Segment Support Assembly

Ta – Tantalum

TMT – Thirty Meter Telescope

Y – Yttrium

Zr – Zirconium

Ø – diameter

Units:

Hz – Hertz

m – meter

mm – millimeter

nm – nanometer

W – Watt

μm – micrometer

2. OVERALL DESCRIPTION

2.1 PERSPECTIVE

The Thirty Meter Telescope is a three mirror design configured as shown in Figure 2. All three telescope mirrors consist of active optical assemblies with thin mirror elements made of low expansion glass or glass ceramic. The Primary Mirror (M1) consists of an assembly of 492 hexagonal optical mirror segments, each mounted on an actuated support assembly that provides rigid body position correction and surface figure correction for each segment. The

Primary Mirror will have 82 spare segments which are used to facilitate efficient recoating of the primary mirror.

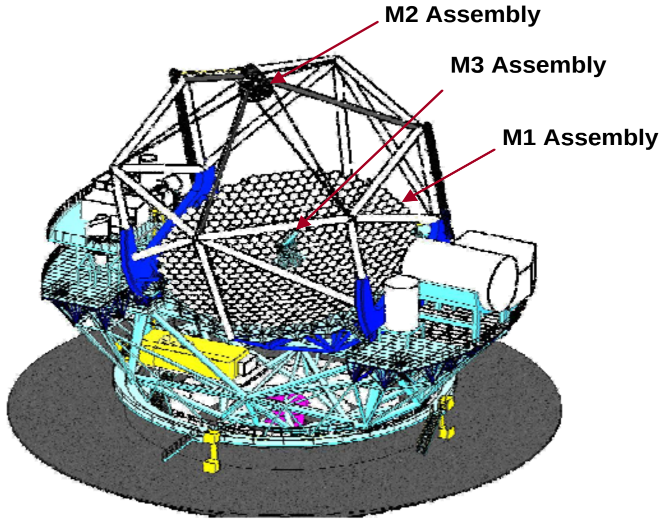

Figure 2. Thirty Meter Telescope

2.1.1 Telescope M1 Segment Size and Optical Prescription

The TMT primary mirror (M1) segments are approximately 1.44 meters diagonally across the hexagon, and 45 mm thick. The optical surface of each segment is nearly spherical and concave, with approximately 5 mm of sag from edge to center. The clear aperture of each segment extends to the edges of the optical surface where there is a 0.5mm chamfer. The segments are arranged having six-fold symmetry. Thus, looking down from M2 towards M1, the primary mirror has six identical sectors of segments arranged at 60º increments around the mirror. Within each of these six sectors of segments, each segment is unique, with a unique aspheric optical prescription and a unique nearly-hexagonal perimeter. This results in M1 being an assembly of 6 sets of 82 unique segments as shown numbered in Figure 7 of Appendix 3.6. Additional features describing the 82 unique segments are documented in RD9, RD12, RD13 and in documents that are referenced therein.

The assembly of segments forms an optical surface with the prescription defined in Table 1. This optical surface forms the primary mirror of the TMT. The full telescope optical design is a Ritchey Chrétien configuration as described in REQ-1-OAD-1000 of AD2. A layout of the optical design is shown in Figure 3 (from AD2).

Table 1. Summary Optical Design Parameters (dimensions in meters)

Surface	Half Diameter of the Beam Footprint (meters)	Radius of Curvature* (meters)	Conic Constant
Primary Mirror	15.00 (to farthest segment corner)	- 60.0	- 1.00095
*Sign convention: positive curvature is convex toward the sky **extracted from RD3			

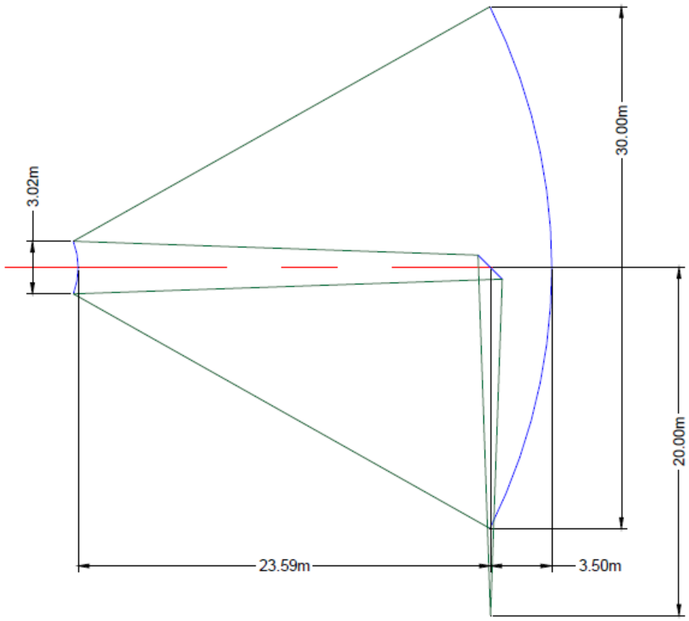

Figure 3. Telescope Optical Design

2.1.2 M1 Segment Maintenance

The M1 mirror segment surfaces will be cleaned frequently while mounted on the telescope using CO_2 snow. The mirror surfaces may also be washed using fluids about two times per year, or cleaned using a strippable polymer cleaning material. The coating must resist corrosion from the environment, and from washing and be hard enough so that dust and particles will not scratch the surface.

During Assembly, Integration and Verification (AIV), the M1 segments will be coated at a rate of two segments per 8 hr day nominally (3 per 12 hr day max). During telescope operation, the M1 segments will be removed from the telescope and recoated at a nominal rate of rate of one per day, with a capability to coat two segments in 8 hours.

The coating must also be strippable so that the entire previous coating can be removed prior to re-applying the new coating, without damaging the polished surface of the segment.

2.1.3 M1 Segment Handling

Figure 4 shows the Mounted Segment Assembly (MSA) which is the assembly of polished mirror segment and Segment Support Assembly (SSA) that will be removed from the telescope for re-coating. The edge sensors, Invar pucks that interface with the axial support flexures and the central diaphragm are bonded to the mirror segment using epoxy adhesive. The MSA has a mass of approximately 225 kg and is ~1.44 meters across the corners, about 1.25 meters across the flats. The height of the assembly is 340 mm from the bottom of the support hardware to the top of the optical surface. RD9 is a drawing of the support assembly that shows the interfaces – but does not include the edge sensors and cabling.

Because of the rapid schedule for segment coating, the quantity of parts bonded to the mirror segment, and the required positional repeatability of the mechanical interfaces; once assembled, the MSA will not be disassembled. To ensure deposition of a coating that meets requirements, the coating chamber and coated surface must be isolated from the components on the back of the segment assembly during coating deposition. This isolation can be accomplished using a back-shell mounted to the back of the segment that envelopes the SSA preventing contaminants from entering the process space.. The back-shell must accommodate irregular segment hexagonal outlines, variable segment thicknesses and the presence of edge sensors. Because of the need to coat the mirror all the way to the edge and the need for edge sensors, the sealing surface must be on the perimeter of the segment rather than the front or back surfaces.

Additionally, to prevent excessive stress in the mirror segment, the volume enclosed by the back-shell must be evacuated along with the processing chamber to prevent high pressure differentials across the mirror segment, and it must be fail safe, such that large pressure differential cannot develop under any circumstances.

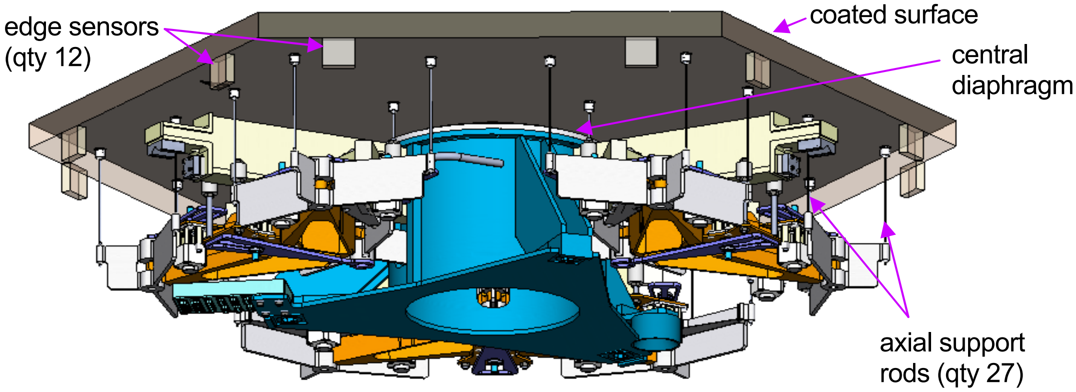

Figure 4. Mounted Segment Assembly - excluding cables

Two methods have been identified that could mitigate the SSA contamination, one active and the other passive. Both methods mount the MSA to a back-shell that envelopes the back of the segment, including the SSA. A flexible perimeter edge seal between the segment and the back-shell contain the contaminants while the optical surface remains exposed.

For the active concept, the back-shell enclosure would be evacuated separately (differentially pumped) to draw off the contaminants while matching the pressure of the coating chamber.

The passive concept for isolation would employ a filter between the sealed back-shell and the coating chamber that would allow the enclosure and the coating chamber to reach the same pressures, but would capture harmful contaminants within the filter and the enclosure volume.

2.1.4 TMT Mirror Coating Laboratory

Because the telescope mirrors are exposed to the summit environment, they must be recoated approximately every 2 years to maintain telescope performance. The quantity of M1 segments dictates continuous coating of segments so that every coating is replaced within the two year schedule. Due to the difficulty and risks of transporting mirror segments, the coating plants for the telescope mirrors may be located at the TMT Summit Facility at an elevation of ~4200 meters in the TMT mirror coating laboratory.

The TMT mirror coating laboratory will contain two coating plants: one for coating M1 segments and another for coating M2 and M3. The coating plants will never be operated at the same time.

The mirror coating laboratory will have two areas: a staging area which is a class 10,000 clean room where segments will be loaded into and out of the coating chamber; and a Service Area behind the clean room that houses the remaining portions of the coating plant that do not need to be located within the clean room. A sealed partition between the clean room area and the service area will prevent air and dust from entering the clean room area. The partition will be designed to mate with the coating plants so that mirrors and segments can be loaded into the coating chamber from the clean room side. A preliminary sketch of the mirror coating laboratory configuration is shown in Figure 5.

The ceiling height of the coating laboratory will be 4 meters minimum. During AIV, a section of exterior wall will be temporarily removed from the building allowing installation of the coating plants. Adjacent to the coating laboratory will be a room for housing the coating plant compressors, cryopumps and roughing pumps, power distribution equipment, gas supplies and other related equipment. A bridge crane will be located in the clean room area, and is available for mirror assembly handling and coating plant functions if required. Another bridge crane is located in the Service Area (TBC) to facilitate maintenance of the coating plants.

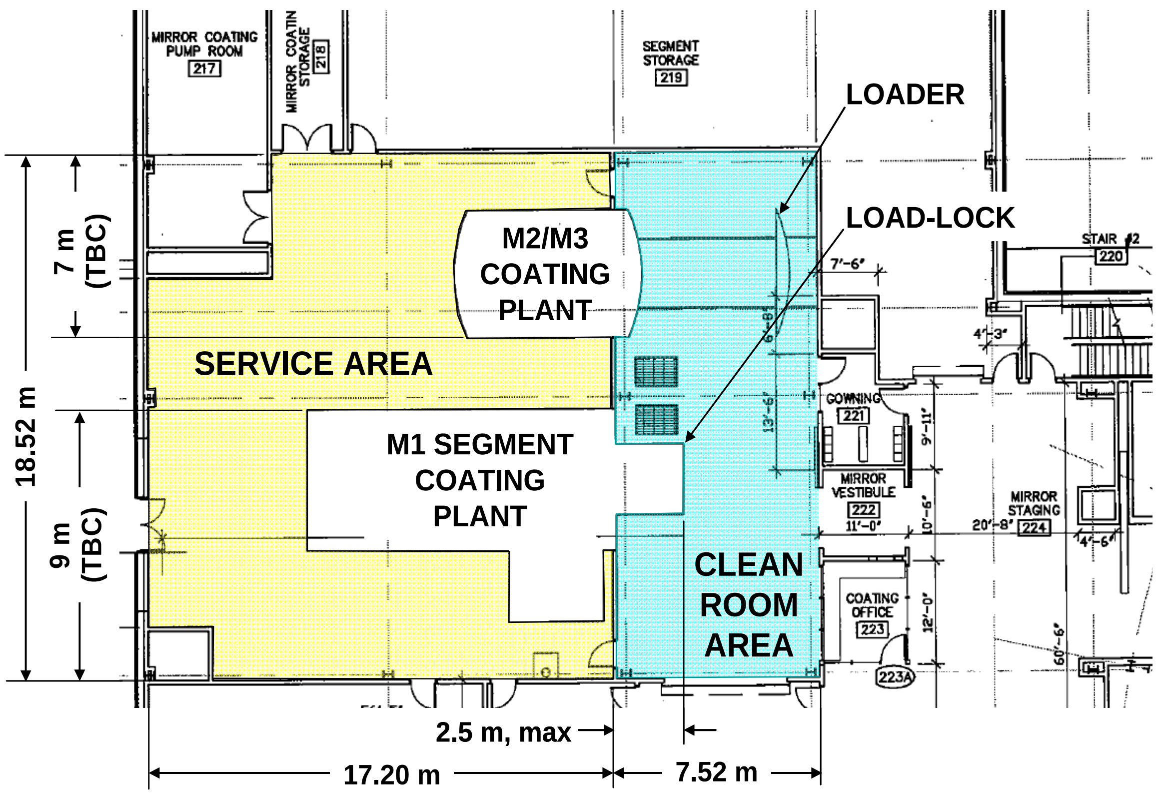

Figure 5. TMT Mirror Coating Laboratory

2.1.5 Baseline Coating Requirements

TMT has determined that for the first light coating on the telescope optics will be based on the four layer protected silver coating used on the Gemini telescopes. This coating is regularly applied at both Gemini Observatories using DC magnetron sputtering deposition. In addition, a similar coating has been successfully implemented on the Kepler Space Telescope primary mirror using an ion assisted evaporative coating process. The Gemini coating meets the minimum durability requirements for the TMT optics, but will require additional development and modification in order to meet the full reflectivity and durability goals of the TMT. Additionally, this coating may be the baseline from which an enhanced coating will be developed in the future.

From RD2, the first-light coating reflectivity requirement is given in Table 2.

Table 2. Minimum reflectivity as a function of wavelength for fresh coatings

Wavelength Range	Requirement	Goal
0.31 - 0.34 µm	N/A	0.8
0.34 - 0.36 µm	0.8	0.9
0.36 - 0.40 µm	0.8 → 0.9	0.9 → 0.95
0.4 - 0.5 µm	0.9 → 0.95	0.95 → 0.98
0.5 - 0.7 µm	0.95 → 0.97	0.98
0.7 – 1.8	0.97	0.98
1.8 - 28 µm	0.97	0.98
The arrow represents linear reflectivity change between the values shown over the given wavelength range.		

From RD8, the Gemini coating consists of the following layers:

Table 3. Layers of the protected silver Gemini coating

Material	**Function**	**Thickness**	**Thickness tolerance**
SiN_x	protector	15 nm	TBD
$NiCrN_x$	adhesor	0.8 nm	TBD
Ag	reflector	200 nm	TBD
$NiCrN_x$	adhesor	5 nm	TBD
substrate			

Additional features of this coating are that robust deposition of the nitride layers is sensitive to the presence of H_2O, so having the capability to achieve 10^{-7} torr pressure to remove all H_2O molecules prior to nitride deposition improves the quality of these layers. Also, the coating reflectivity versus wavelength is very sensitive to the thickness of the two outer nitride layers.

Also, it is important to note that the silver layer must be dense and small grained. Surface Plasmon Resonance (SPR) within silver produces significant absorption in UV/blue wavelengths when the roughness or grain size of the silver is too large. To prevent this, the silver should be deposited rapidly on a cold substrate, thus forming dense small grains and minimizing SPR response.

In summary, the TMT coatings must meet the following general constraints:

- Coatings must be efficient for science:
  - Must be highly reflective
    - Must work over ~2 decades in wavelength (0.31 -- 28 µm).
    - Must have low IR emissivity (i.e., reflectance in IR must be high)
  - Reflectance shall vary slowly with wavelength to enable data interpretation
  - Coating must work at a range of incidence angles.
- Coating must have excellent longevity to reduce operation costs and risks:
  - With 492 M1 segments, recoating every two years requires coating 5 segments per week. Longer lasting coatings will significantly reduce cost.
  - Risk of damage to segments increases with frequency of removal, stripping, coating and reinserting. Less frequent recoating will significantly reduce risk.
  - Coating should be easily strippable with no resultant damage to the optical substrate.

- Coating must be mechanically robust to withstand ~2-10 yrs regular cleaning with CO_2 snow and washing.
  - Coating should adhere well to substrate
  - Coating shall not be soft
  - Coating must not react or corrode when exposed to CO_2 or the fluids used for washing.
- Stress should be low (or predictable):
  - With thin substrates, stress induced between the coating and the mirror element can deform the optical figure.
  - Non-uniformity or non-repeatability in the resulting stress may deform the optical figure in a manner that is not be fully compensated using the adaptive actuators for each element.
- Coating shall be uniform
  - Thickness shall be uniform so that the mirror surface figures are unchanged due to dimensional variation or by stress variation
  - Reflectivity shall be uniform across the clear aperture of the coated mirror.

2.1.6 Future Coating Development

Because silver is the only metal that meets TMT reflectivity requirement goals over most of the TMT wavelength range [RD10], it is assumed that future coating development will use silver for the primary reflecting material. Silver adheres poorly to glass requiring an adhesion layer, needs protection to prevent tarnishing, and requires enhancement in the UV to meet reflectivity goals.

The materials that will be used to enhance the TMT mirror coatings are not determined yet. Early studies described in RD10 have indicated that a possible substitute for the Gemini undercoat of NiCrN might be based on Yttrium oxide with both good adhesion to silver and solubility in dilute acids so that the coating can be stripped. Possible substitutes for the Gemini protection layers may be oxides and nitrides based on Si, Hf, Ta, Zr, Y, Sc, Nb, Gd, and Ti This list of materials is not intended to be complete.

2.1.7 Proposed M1 Segment Coating Plant Architecture

Preliminary coating plant studies have developed a possible M1 segment coating plant architecture that provides an automated, precise, repeatable, high yield process. The proposed architecture for the M1 segment coating plant consists of an arrangement of zones for segment processing. The segment would be attached to the sealed back-shell with the mirror surface exposed. The back-shell can interface with transport hardware that moves the mirror segment through the coating plant into different zones if required. The sealed back-shell prevents contamination to the coating chamber environment from out-gassing of mechanical components of the SSA that are attached to the back of the mirror segment. The back-shell, with segment attached, would be placed into the automated coating plant and would include a simple interface within the chamber system for sealing and mechanical transport as needed. The coating chamber would consist of the following zones separated by partitions:

- An entry/exit load-lock where the segment and back-shell are loaded into the chamber and fastened to the mechanical transport system as required.
  - This is the only portion of the system that is not continuously maintained at a vacuum
  - This zone will be evacuated and the optical surface of the mirror will be automatically baked and plasma-cleaned in preparation to coating
- Deposition Zone 1
  - used to automatically deposit NiCrN layers for first light coating

- Deposition Zone 2
  - used to automatically deposit Ag layer for first light coating
- Deposition Zone 3
  - used to automatically deposit SiN_x layer for first light coating

The M1 mirror surface to be coated should face either horizontally or downward during coating deposition to minimize particulates and pinholes on the coated surface.

Each deposition zone will be designed to contain two magnetron sputtering sources sized to provide uniform deposition layers and additional gas lines for introducing reactive gases. For first light, the sources required are only those that will produce the layers for the Gemini protected silver coating. Ports for additional sources shall be planned to enable coating enhancement. During deposition of first-light coatings, the additional ports shall be blanked-off.

The sputtering sources shall be designed such that the distance between the target and the mirror can be varied from 10mm (TBC) to 100mm (TBC) to provide process flexibility. Gas distribution manifolds, low angle sputter shielding and vacuum control hardware will be incorporated into each deposition zone to suit process requirements. Relative motion between the mirror segment and the sources shall be provided, as necessary to deposit the requisite coatings on the mirror surface. Valves and baffling will provide isolation between zones as needed. Provisions for physical film thickness monitoring are required.

2.2 SYSTEM FUNCTIONS

The coating plant for the M1 segments must deposit coatings that meet the requirements of RD2 including high reflectivity across a broad wavelength range, environmental durability, uniform thickness with film stress that is low and uniform. The coatings must survive frequent cleaning with CO_2 snow and must also be strippable without damage to the substrate so that the substrates may be periodically recoated to recover full performance.

The coating plant will be designed for high through-put of M1 segments.

The coating plant must include the capability to prevent contaminants from the SSA from migrating into the process space.

The coating plant must have the ability to be upgraded to enable coating with additional material layers in the future.

During observatory operations, the coating plant shall be operated during the day shift, but the plant shall return to idle prior to the start of observing each night so as to minimize disturbance to the environment that could degrade science operations. While at idle, the system shall be maintained at the minimum state that enables rapid activation following observing. As such, it is anticipated that cryo-pumps will need to continue to operate 24 hours per day, 7 days per week.

2.3 USER AND OPERATOR CHARACTERISTICS

The M1 segment coating plant will be automated and software-driven to ensure safe, repeatable, rapid application of high quality coatings. Even so, experienced personnel who are trained in optics handling will be required to handle the M1 segments while loading and unloading from the coating plant.

2.4 EXTERNAL INTERFACES

The M1 Segment Coating Plant will interface with the following subsystems:

Subsystem: M1 Segments

- Interface Control Document: TBD
- Critical interface issues:
  - Mechanical interface between M1 segments and coating chamber
  - Mechanical method to prevent coating contamination due to M1 Segment Support Assembly

Subsystem: TMT Observatory Facilities

- Interface Control Document: TBD
- Critical interface issues:
  - Facilities must provide a Class 10,000 clean room arrangement to prevent dust from falling on optical surfaces after coating has been stripped and before segment is installed and sealed into coating plant.
  - The coating plant subsystem must work with Facilities to determine the location of vacuum chamber pumps and pressure control to ensure uniform vacuum conditions within the coating plant that will result in high quality, uniformly thick coating layer deposition.
  - Facilities must provide a supply of power, coolant, processing and source gases for coating plant function. The coating plant subsystem must identify the plant requirements and any safety issues related to coating materials storage, handling and stability.
  - TMT observatory requires environmental constraints on electromagnetic interference (EMI), vibration and thermal dissipation from the coating plant including pumps, and compressors.
  - Required hardware (such as cranes) for loading and unloading the coating plant will be provided by the TMT Observatory Facilities subsystem. Interfaces must be developed between the coating plant subsystem and Facilities.

2.5 CONSTRAINTS

a. Regulatory policies
   - Some coatings may require source materials that present potential hazards to personnel and equipment. The coating plant shall incorporate hardware and safety features to ensure the safety of personnel and equipment. The coating plant, all source materials and all coating byproducts must comply with local regulations regarding safe storage, handling, and disposition of dangerous materials.

b. Hardware limitations
   - Any EMI, vibrations and heat introduced by the coating plant into the TMT observatory environment must be less than specified limits.

c. Software limitations
   - Since the coating deposition must be very repeatable, the software recipes for the coating must be password protected, robust and not be easily changeable or corruptible.

- Since the coating deposition will be unique for this coating plant and mirror arrangement, the ability to adjust the process recipe to permit optimization of the resulting coating layer deposition must be provided.
- Since the coating deposition recipe may change in the future, it must be possible to update the recipe to include changes. The software must be well documented to allow recipe changes when required.

d. Audit (troubleshooting) functions

- In case of coating plant failure, troubleshooting functions shall be provided to enable identification of the failed components.
- Safety features shall be provided to enable safe shut down of the coating plant in the event of any component failure or loss of power.

2.6 ASSUMPTIONS AND DEPENDENCIES

The coating plant for TMT shall be designed to reproduce the four-layer Gemini protected silver coating for first light operations. This document provides requirements that shall guide the deposition of a Gemini-like coating. In addition, the coating plant must be designed to allow for additional source materials so that it can be augmented in the future to provide a coating that is enhanced to provide improved reflectivity performance. The reflectivity requirements are dependent on the requirements of the instruments of the TMT Observatory. Changes in instrument requirements will change the reflectivity requirements for the coating and the specifications for the coating plant.

The current plan for maintenance of the M1 segment coatings is frequent CO_2 snow cleaning, infrequent fluid washing, along with stripping and recoating every two years. It is a goal to have the coatings last for 5 years between reapplying coatings.

3. SPECIFIC REQUIREMENTS

3.1 GENERAL CONSTRAINTS

[REQ-2-M1CP-0110] The M1 segment coating plant shall be compliant with international SEMI S2 standards.

3.2 ENVIRONMENTAL CONSTRAINTS

[REQ-2-M1CP-0210] The M1 segment coating plant shall operate at the manufacturer's facility and at any elevation between sea-level and 4200 meters with correct values for system pressure measurements and full functionality.

Discussion: The coating plant shall be fully tested and shall produce coated samples that meet the requirements described herein while at the manufacturer's facility and after installation and commissioning at any TMT Observatory facility. The change in elevation between locations shall cause no degradation in performance of the coating plant.

Discussion: Pressure gauges may be recalibrated upon arrival at the TMT Observatory if necessary.

[REQ-2-M1CP-0220] During daytime coating operations, the M1 segment coating plant shall dissipate no more than an average of 44 kW of heat per day to the air with a goal of 20kW and no more than an average of 17 kW of heat per day to facility coolant with a goal of 10kW.

Discussion: Daytime is defined as 10 hours centered around noon.

Discussion: The dissipation power levels are from RD11.

[REQ-2-M1CP-0230] During nighttime, the M1 segment coating plant shall dissipate no more than an average of 32 kW of heat to the air during the nighttime with a goal of 10kW and no more than an average of 13 kW of heat during the nighttime to facility coolant with a goal of 5kW.

Discussion: Nighttime is defined as 14 hours centered around midnight.

Discussion: The dissipation power levels are from RD11.

[REQ-2-M1CP-0240] During nighttime telescope operations, the vibrating components of the M1 segment coating plant shall be isolated to transfer less than TBD vibration to the facility structure.

Discussion: The cryo-pumps will maintain vacuum in the M1 segment coating plant continuously. The pump heads and the compressor that provides cooled liquid to the pumps must be isolated from the facility structure to prevent vibration transfer to the telescope that may degrade telescope function.

3.3 FUNCTIONAL REQUIREMENTS

3.3.1 Load-lock Requirements

[REQ-2-M1CP-0310] The M1 segment and back-shell shall be loaded into a load-lock that is vacuum-sealed from the process chamber. When the load-lock is evacuated, the vacuum-seal port leading to the process chamber can be opened so that the segment may enter the process chamber.

Discussion: The load-lock cycles between ambient room pressure and vacuum. The segments will be loaded into the coating plant at the load-lock.

Discussion: The load-lock will provide an evacuated volume for interface into the process chamber. The process chamber where layers are applied must achieve high vacuum and be free of oxygen and H_2O, thus it will be continuously evacuated to enable rapid pump down to meet the required coating schedule.

[REQ-2-M1CP-0311 The load-lock chamber shall incorporate heating and plasma cleaning equipment. After evacuation of the load-lock and back-shell, the mirror surface shall be heated to less than 80º C and plasma cleaned.

Discussion: Following this process, the mirror surface must be ready for coating. No damage to the mirror surface shall occur during plasma cleaning.

[REQ-2-M1CP-0312] The load-lock shall have independent pressure control using clean dry Nitrogen or clean dry air to back fill when pressure is raised to ambient.

Discussion: The load-lock cycles between ambient room pressure and vacuum. The segments will be loaded into the coating plant at the load-lock.

[REQ-2-M1CP-0312] The load-lock port shall open into the clean room within the coating laboratory facility. There shall be a seal between the M1 Coating Plant and the clean room wall to prevent air exchange from the uncontrolled service area where the rest of the coating plant is located.

[REQ-2-M1CP-0313] The load-lock port shall not extend into the clean room more than 2.5 m.

[REQ-2-M1CP-0314] The load-lock port shall be configured such that the segment and back-shell can be placed onto the transport stage using an overhead crane having a maximum hook height of 4m and a travel range that extends to within 1m (TBC) of the clean room wall.

[REQ-2-M1CP-0315] The force required by the operator to open/close the load-lock port shall not exceed 100N.

3.3.2 Coating Deposition Requirements

[REQ-2-M1CP-0320] The coating plant shall be able to deposit coating layers described in Table 3 onto the M1 segments in the order and with the thicknesses described in Table 3.

[REQ-2-M1CP-0321] The coating plant shall be able to deposit a reflective coating onto the M1 segments that meets the requirements specified in Appendix 3.8.

[REQ-2-M1CP-0322] During mirror coating, the coating chamber shall have the vacuum pumping capability to reach and maintain a pressure as low as $1x10^{-7}$ torr within a period of time sufficient to meet the throughput requirements.

Discussion: This low pressure is used to remove contaminants from the coating chamber prior to deposition.

[REQ-2-M1CP-0324] The coating plant shall have capacity for upgrading the coating recipe to enhance the coating performance to meet the goals specified herein. The provision for upgrade shall include three additional ports for additional magnetrons and additional power lines, gas lines and coolant plumbing to enable process variation.

Discussion: The additional gas lines shall include MFCs, and isolation and control valves. The additional ports and gas lines shall be purged with inert gas and sealed upon delivery of the hardware.

[REQ-2-M1CP-0326] Any reactive gas lines shall have the capability to be purged with inert gas and evacuated.

[REQ-2-M1CP-0328] Sensors must be incorporated in the design to monitor the thickness of the deposited layers.

[REQ-2-M1CP-0329] The M1 segment mirror surface being coated shall face either horizontally or downward during coating layer deposition.

Discussion: This orientation will minimize pinholes and particulates on the coated surface.

3.3.3 M1 Segment Assembly Handling Requirements

[REQ-2-M1CP-0330] The Mounted Segment Assembly (MSA) shall be enclosed in a sealed back-shell with the optical mirror surface exposed during the coating process to prevent contamination from materials of the MSA from degrading the coating.

[REQ-2-M1CP-0332] The temporary seal between the back-shell and the M1 mirror segment shall be flexible and be applied between the perimeter of the hexagon segment and the back-shell, sealing the passage between the segment and the back-shell.

Discussion: The seal may be fabricated from aluminum foil, foil tape, Kapton tape or other very low outgassing, compliant materials suitable for this purpose.

[REQ-2-M1CP-0334] The volume between the back-shell and the mirror segment shall be evacuated simultaneously with the coating chamber in order to maintain pressure equilibrium within the two volumes to better than 0.5 torr at all times. The pressure control of the back-shell and coating chamber shall be fail safe, and shall prevent pressure differentials to develop in excess of 0.5 torr during any potential coating plant failure,

Discussion: A 0.5 torr differential pressure results in an average force across the mirror segment area of 91 Newtons. This differential pressure may be achieved though active pressure control of both volumes. It may be possible to provide a filtered passage between the two chambers to passively maintain the differential pressure at an acceptable level. The filter would be required to prevent passage of any contaminants from the SSA. Thus, all materials out-gassed from the plastics, oils, etc. within the SSA would be confined to the enclosure pod.

3.3.4 Process Throughput

[REQ-2-M1CP-0340] The coating plant shall be capable of depositing the 4-layer protected silver Gemini coating, or an advanced 6-layer coating at a rate of one segment every four hours, continuously between maintenance intervals.

Discussion: During normal observatory operations, the coating plant shall be capable of coating 10 segments per week within normal working shifts of eight hours. This capability will not be exercised all the time, but is required to meet the required recoating schedule. During AIV, the segment coating rate shall be accelerated to 20 per week. The accelerated AIV rate may depend on adding additional working shifts.

Discussion: During AIV and the subsequent TBD coating cycles, the 4-layer protected silver Gemini coating will be applied. Any enhanced coating design must meet the 10 coatings per week schedule assuming up to 6 deposition layers..

3.3.5 Coating Plant Controls Requirements

[REQ-2-M1CP-0350] The coating plant shall be instrumented to permit automatic segment cleaning and coating deposition.

Discussion: The segments will be manually loaded into the load-lock and the load-lock shall be manually closed. Following closing the load-lock port, the baking, plasma cleaning, and coating layer deposition shall proceed automatically.

[REQ-2-M1CP-0352] Sensors shall be incorporated into the design of the coating plant so that maintenance and functionality can be monitored automatically.

[REQ-2-M1CP-0354] In case of coating plant failure, troubleshooting functions shall be provided to enable identification of the failed components.

3.3.6 Coating Plant Software Requirements

[REQ-2-M1CP-0360] The software controlling the coating plant shall be PLC-based with a user-friendly PC-supported graphical user interface.

[REQ-2-M1CP-0362] The software shall be recipe driven with password protection to prevent inadvertent recipe modification.

[REQ-2-M1CP-0364] Coating data shall be collected and stored automatically for each coating run.

[REQ-2-M1CP-0366] The control software shall have an Ethernet data pipeline to enable remote access to process data and system status.

Discussion: Coating plant functionality and safety shall be monitored with a safety system that will be described in Paragraph 3.5.3.

3.4 COATING PERFORMANCE REQUIREMENTS

Discussion: The coating performance requirements are detailed in RD2 and are listed in Appendix II below.

3.5 SYSTEM ATTRIBUTES

[REQ-2-M1CP-0500] The coating plant shall interface with the TMT coating laboratory facility with the load-lock port opening into the clean room area, a seal between the load-lock port and the rest of the coating plant, and the remaining portion of the coating plant located in the service area.

Discussion: The load-lock port protrudes into the clean room, while the remainder of the coating plant resides in the Service Area. The coating plant has a collar that interfaces with the clean room wall, forming a seal at the transition to the loading port.

[REQ-2-M1CP-0502] The roughing pump and cryopump compressors shall be vibration isolated and located in an adjacent pump room that is located TBD meters from the coating plant.

Discussion: Vibration isolation shall address vibration from the mounting feet of the pumps and compressors as well as the vibration from secondary paths such as electrical conduit, pipes, and hoses.

[REQ-2-M1CP-0504] The TMT coating laboratory facilities shall supply the features listed in Table 5 for the coating plant use.

[*Table 5. Coating Plant Facilities Interface Definition*

Feature	**Requirement (TBC)**
Power	400 Amps, 120Y208 V/ 3 phase, 60 Hz
Cryopump Power	100W, and has a 1.14A current draw per pump
Coolant	Water: temperature: 20 to 25ºC, up to 20 gpm @ 65 psig
Nitrogen	100 psig
Clean Dry Air	100 psig
Argon	TBD liters per minute during coating deposition

[REQ-2-M1CP-0506] The coating plant shall be sized to fit within the shared volume shown in *Figure 5* with adequate service area around the coating plant to provide access for all maintenance and repair activities. The M2 and M3 coating plant will share the service volume and must be accommodated.

[REQ-2-M1CP-0507] The coating plant shall be able to coat a minimum of 50 segments between servicing intervals.

3.5.1 Reliability

[REQ-2-M1CP-0510] The coating plant shall be designed to operate with regular maintenance and repair as required for 50 years.

[REQ-2-M1CP-0512] The coating plant shall be designed so that failure and maintenance results in downtime occurring less than 14 days per year.

[REQ-2-M1CP-0514] The coating plant design shall include sensors to monitor maintenance requirements and safety issues.

3.5.2 Availability

[REQ-2-M1CP-0520] Any components that require replacement shall either be readily available with vendor and part number supplied or shall be provided as spares upon delivery of the coating plant.

3.5.3 Safety and Security

[REQ-2-M1CP-0530] Alarms, interlocks and sensors shall be incorporated in the design of the coating plant to monitor unsafe conditions, produce appropriate alarms, and automatically shut down the coating plant safely.

[REQ-2-M1CP-0532] In the event of any component failure or power loss from any reason, the safety system shall enable safe shut down of the coating plant to protect personnel, mirrors and the coating plant.

[REQ-2-M1CP-0534] The coating plant shall have an emergency stop (E-Stop) switch that will place the equipment into a safe shutdown condition when activated. Said E-Stop shall not be linked to the Observatory safety systems.

[REQ-2-M1CP-0536] The coating plant shall be designed with features that protect the mirror segment from damage in the event of any mechanism or control system failure.

Discussion: The system shall be fail-safe. No single point failure shall result in damage to the mirror segment.

3.5.4 Maintainability

[REQ-2-M1CP-0540] The coating plant shall be designed to facilitate servicing, by providing access to all subsystems, with the ability to remove and replace components that might require service or replacement.

Discussion: All maintenance must take place within 4 hour periods during times when only one segment per day is being coated.

[REQ-2-M1CP-0542] A detailed manual describing the function of the coating plant, the components, replacement, upgrading, repair and maintenance shall be delivered along with the coating plant.

[REQ-2-M1CP-0544] As much as possible, maintenance of the coating plant shall be planned to take place with access from the Service Area. Only when necessary for load-lock maintenance shall maintenance take place with access from the clean room area.

3.5.5 Seismic Safety

[REQ-2-M1CP-0550] The M1 Coating Plant and all subsystems shall withstand earthquakes up to the levels of a 10-year return period earthquake without injury to personnel, a mirror segment that is contained within the coating plant, or the coating plant,. The system shall be designed to TBDg horizontal, and TBDg vertical quasi-static loads assumed to act independently, in addition to gravity and atmospheric pressure. Particular attention shall be paid to the management of hazardous gases. It shall be possible for the coating operations staff to perform an inspection of the system within 8 hours after said earthquake. The inspection shall be sufficient to ensure the coating plant is in a safe condition to allow resumed coating operations to take place.

Discussion: Inspection would be expected to start after any potentially damaging event once the danger has passed and staff have returned to work.

[REQ-2-M1CP-0551] The M1 Coating Plant and all subsystems shall withstand earthquakes up to the levels of a 200-year return period earthquake without injury to personnel, damage to a mirror segment that is contained within the coating plant, with coating plant damage limited to $100,000 (2009 US Dollars) in value. The system shall be designed to +/-TBDg horizontal, and +/-TBDg vertical quasi-static loads, assumed to act independently, in addition to gravity and atmospheric pressure. Particular attention shall be paid to the management of hazardous gases. After inspection and repair, coating plant shall be capable of resumed coating operation within 12 weeks.

[REQ-2-M1CP-0552] The M1 Coating Plant and all subsystems shall withstand earthquakes up to the levels of a 1000-year return period earthquake without injury to personnel, damage to a mirror segment that is contained within the coating plant, with coating plant damage limited to $200,000 (2009 US Dollars) in value. The system shall be designed to +/-TBDg horizontal, and +/-TBDg vertical quasi-static loads, assumed to act independently, in addition to gravity and atmospheric pressure. Particular attention shall be paid to the management of hazardous gases.

[REQ-2-M1CP-0553] The coating plant shall be equipped with an accelerometer and control system that will shut down the coating plant in a safe manner should accelerations exceed 0.1g(TBC) in any direction.

[REQ-2-M1CP-0554] The coating plant and associated equipment shall be securely mounted to the floor of the facility to prevent overturning in the event of an earthquake. Such mounting shall be compatible with vibration isolation required per [REQ-2-M1CP-0502].

APPENDIX

I. COORDINATE SYSTEMS DESCRIBING THE M1 SEGMENTS

The four coordinate systems described below are excerpted from RD1 and enable the definition of each unique segment.

a. ELEVATION COORDINATE SYSTEM (ECRS) AND M1 COORDINATE SYSTEM (M1CRS)

The ECRS and M1CRS are parallel but offset from each other. The offset distance is 3.5 meters in the Z direction. The M1 Segment Coordinate System described below is referenced from the ECRS.

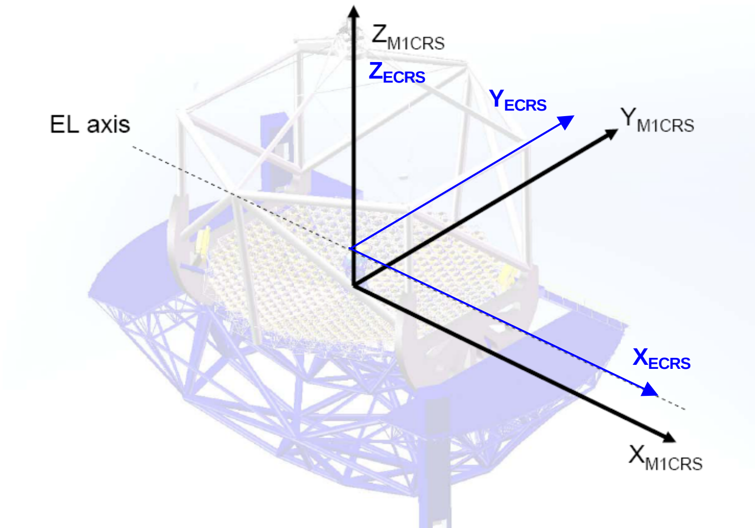

Figure 6. The Elevation Coordinate System and M1 Coordinate System

b. M1 SEGMENT COORDINATE SYSTEM (SCRSJ FOR THE J^TH SEGMENT)

The SCRSj provides a coordinate system for each segment that can be described and located from the ECRS.

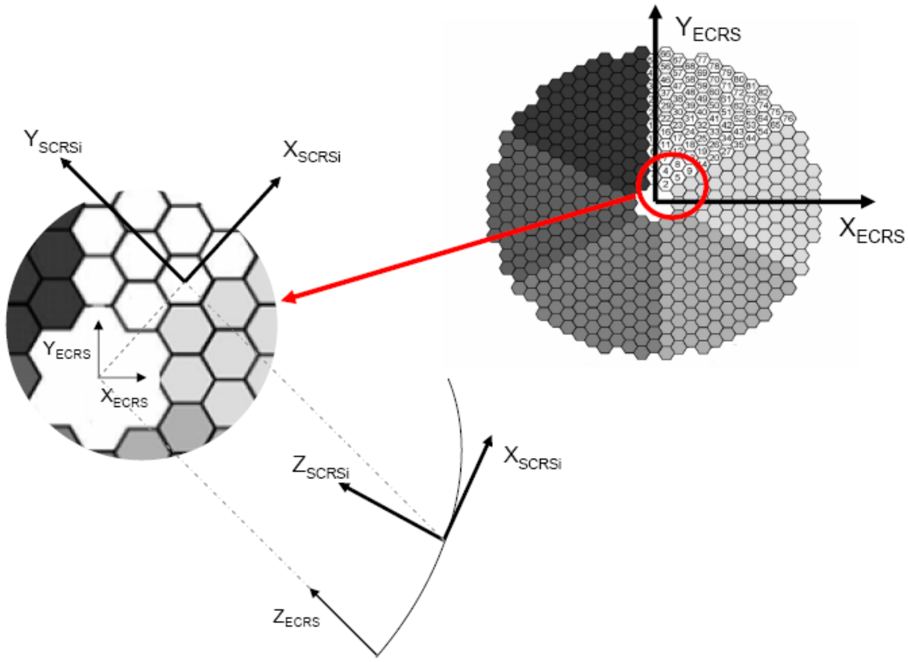

Figure 7. The Segment Coordinate System, j^th segment (SCRSj)

c. PRIMARY SEGMENT ASSEMBLY COORDINATE SYSTEM

The Primary Segment Assembly Coordinate System provides a way to describe the deviation of the segment perimeter from a perfect hexagon. It also shows the mounting orientation for each segment relative to the segment support assembly (SSA) that is common for all segments.

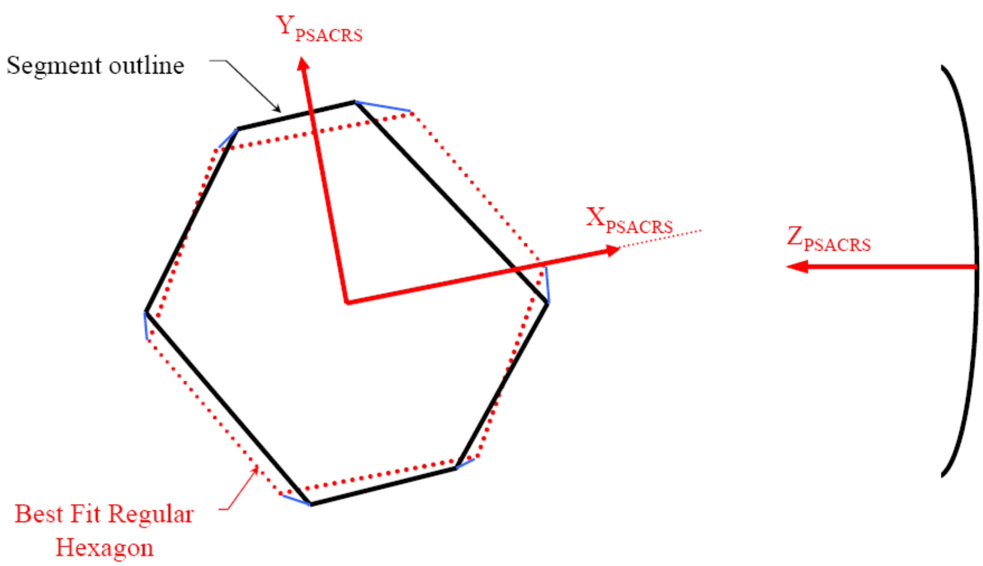

Figure 8. Primary Segment Assembly Coordinate System

d. LOCATION OF THE MIRROR SURFACE FOR EACH M1 SEGMENT WITH RESPECT TO MOUNTING FEATURES

Information on the location of each mirror surface for each M1 segment can be found in the following reference documents:

- RD12 is a listing of the M1 Segment database that describes locations of segment vertices in local coordinate systems (PSACRS).
- RD13 is a drawing of an M1 Segment providing details of the segment edges.
- RD9 is a drawing of the M1 segment mounted to the segment support hardware.

II. REQUIREMENTS FOR REFLECTIVE OPTICAL COATINGS, FROM RD2

Discussion: This section includes requirements from AD1, AD2, and RD2.

a. PERFORMANCE REQUIREMENTS

i. Reflectivity Requirements

[REQ-2-CO-1100] The reflectivity of a freshly applied coating for M1 segments, M2 and M3 at first light shall equal or exceed the values given in the Requirement column of Table 2 for the wavelength bands specified.

Table 2. Minimum reflectivity as a function of wavelength for fresh coatings at the prescribed angles of incidence shown in Table 3.

Range	Requirement	Goal
0.31 - 0.34 μm	N/A	0.8
0.34 - 0.36 μm	0.8	0.9
0.36 - 0.40 μm	0.8 → 0.9	0.9 → 0.95
0.4 - 0.5 μm	0.9 → 0.95	0.95 → 0.98
0.5 - 0.7 μm	0.95 → 0.97	0.98
0.7 – 1.8	0.97	0.98
1.8 - 28 μm	0.97	0.98

Discussion: An arrow in the Requirement column indicates that the reflectivity requirement in that range varies linearly from the first value specified at the lower end of the wavelength range to the second value specified at the higher end of the wavelength range.

Discussion: This distribution of reflectance is nearly met by the performance of the Gemini protected silver coating as reported in RD8.

[REQ-2-CO-1102] The reflectivity of a freshly applied coating as a function of wavelength presented in Table 2 shall diminish <0.5% as the angles of incidence change across the mirror element surfaces over the ranges shown in *Table 3*.

Table 3. Range of angles of incidence for reflection at each mirror surface.

Mirror Element	Angles of Incidence	
	Minimum	Maximum
M1 Segment	0°	14.4°
M2	0°	14.1°
M3	32°	48°

[REQ-2-CO-1103] For fresh new coatings, the reflectance of the coating at a single angle of incidence over the surface of the coated element over the wavelength range from 0.31 to 28 μm shall be uniform within the following limits:

M1 segments:

±0.3% across the segment surface averaged from discrete measurements of roughly 10 mm diameter spots

M2:

±0.3% across the element surface averaged from discrete measurements of roughly 10 mm diameter spots

M3:

±0.2% across the element surface averaged from discrete measurements of roughly 10 mm diameter spots

ii. Emissivity Requirements

[REQ-2-CO-1200] The emissivity of a freshly applied coating for M1 segments, M2 and M3 at first light, over the wavelength range of 0.7 to 28 um, shall be less than or equal to 0.015.

Discussion: The performance of the Gemini coating complies with this requirement per RD8.

Discussion: As a goal, the emissivity of each surface should be less than 0.013.

iii. Change of reflectivity with wavelength

[REQ-2-CO-1300] The variation of reflectivity of the coating with wavelength shall be less than 0.003 per nm of wavelength.

iv. Polarization

[REQ-2-CO-1400] The phase shift of light shall be less than 22º when reflected with an angle of incidence of 45º off a freshly coated optical surface.

Discussion: The performance of the Gemini coating complies with this requirement per RD8.

v. Coating thickness uniformity

[REQ-2-CO-1500] The optical surface figure change of the M1 segments, due to total coating thickness non-uniformity, shall be segregated into two types: correctable and non-correctable. The correctable low spatial frequency thickness variation up to Zernike 3rd order shall be less than 50nmRMS (TBC). The non-correctable thickness variation for 4th order and above shall be less that 5nm RMS (TBC)

Discussion: The M1 segments have active supports that are able to correct low-spatial-frequency shape errors up to and including 3rd order Zernikes. Shape errors having spatial frequencies above 3rd order are not correctable by the supports, and therefore they impact performance more significantly.

[REQ-2-CO-1501] The optical surface figure change of the M2 and M3, due to total coating thickness non-uniformity, shall be segregated into two types: correctable and non-correctable. The correctable low spatial frequency thickness variation up to Zernike 3rd order shall be less than 50nmRMS (TBC). The non-correctable thickness variation for 4th order and above shall be less that 5nm RMS (TBC)

Discussion: The M2 and M3 low-spatial frequency errors are correctable by reshaping the M1 to compensate. Higher-spatial frequency errors are not correctable on the M1 and therefore they impact performance more significantly.

vi. Coating-induced deformation of optical surface

[REQ-2-CO-1600] For the M1 segments, the allowable amount of repeatable defocus of the optical surface from coating-induced stress shall not exceed 200 nm peak-to-valley.

[REQ-2-CO-1602] Relative to the average optical surface defocus of all the M1 segments caused by coating-induced stress, the optical surface defocus of any individual segment shall not deviate by more than 40 nm peak-to-valley.

[REQ-2-CO-1604] For the M1 segments, the allowable amount of optical surface deformation, described by Astigmatism, Coma, and Trefoil, from coating-induced stress shall not exceed 20 nm peak-to-valley.

[REQ-2-CO-1605] For the M1 segments, the allowable amount of optical surface deformation, described by 4th order Zernikes and higher, from coating-induced stress shall not exceed 5 nm peak-to-valley.

[REQ-2-CO-1606] For the M2, the allowable amount of repeatable defocus of the optical surface from coating-induced stress shall not exceed 200 nm peak-to-valley.

[REQ-2-CO-1608] For the M2, the variation in defocus of the optical surface from coating-induced stress, from one coating application to the next, shall not exceed 100 nm peak-to-valley.

[REQ-2-CO-1610] For the M2, the allowable amount of optical surface deformation, described by Astigmatism, Coma, and Trefoil,, from coating-induced stress shall not exceed 40 nm peak-to-valley.

[REQ-2-CO-1611] For the M2, the allowable amount of optical surface deformation, described by 4th order Zernikes and higher, from coating-induced stress shall not exceed 5 nm peak-to-valley.

[REQ-2-CO-1612] For the M3, the allowable amount of repeatable defocus of the optical surface from coating-induced stress shall not exceed 400 nm peak-to-valley.

[REQ-2-CO-1614] For the M3, the variation in defocus of the optical surface from coating-induced stress, from one coating application to the next, shall not exceed 200 nm peak-to-valley.

[REQ-2-CO-1616] For the M3, the allowable amount of optical surface deformation, described by Astigmatism, Coma, and Trefoil, from coating-induced stress shall not exceed 80 nm peak-to-valley.

[REQ-2-CO-1617] For the M3, the allowable amount of optical surface deformation, described by 4th order Zernikes and higher, from coating-induced stress shall not exceed 5 nm peak-to-valley.

Discussion: Neither the final coating nor the coating process shall induce excessive non-uniform stress (surface warping) in mirror substrates, in excess of the optical uniformity requirement. Some defocus is acceptable, provided it is repeatable from segment to segment.

vii. Coating process constraints

[REQ-2-CO-1700] At no time during the coating process shall the temperature of any portion of the glass or glass ceramic mirror substrate exceed 100° C.

Discussion: This is to ensure dimensional stability of the substrate

[REQ-2-CO-1702] At no time during the coating process shall the temperature of the adhesive used to bond attachments to the back surface of the glass or glass ceramic substrate exceed 80° C.

Discussion: This is to ensure stability of the adhesive.

[REQ-2-CO-1704] The coating deposition shall be compatible with a coating plant that can achieve a base pressure of 1×10^{-7} torr with the optic loaded and pumped down..

Discussion: For example, contamination of silicon nitride layers with oxygen and H_2O is a concern. Pumping down to lower than 3×10^{-7} torr has been recommended.

[REQ-2-CO-1706] The deposition rate for the silver layer shall be high enough to avoid a reduction in reflectivity caused by surface plasmons.

Discussion: Rates higher than 2 nm per second have been recommended.

viii. Coating Durability

[REQ-2-CO-1800] The coating shall meet the performance requirements specified herein, during normal operation, for a period of no less than two years (5 years as a goal) when maintained using the cleaning methods and frequencies specified in 3.2.3.

b. ENVIRONMENTAL, CHEMICAL AND PHYSICAL CONSTRAINTS

i. Coating Visual Inspection

[REQ-2-CO-2100] Visual inspection shall be performed per MIL-C-48497 Revision A, Section 4.5.2.5.2.

[REQ-2-CO-2102] The freshly applied coatings shall have no pinholes larger than 10 µm in diameter, fewer than 5 pinholes that are approximately 5-10 µm in diameter, and fewer than 5 pinholes that are < 5 µm in diameter within any 30mm x 30 mm area within the clear aperture of the coated substrate as determined by visual inspection.

Discussion: As stated in RD11, section 4.5, pinholes are caused by dust on the surface during coating deposition. By keeping the coating chamber and mirror substrates free of dust, the pinholes in the coating will be minimized. The facility for coating TMT mirrors will have a clean room at the coating plant load/unload stations.

Discussion: The pinhole size and quantity listed above are from RD11 and were obtained during Gemini coating deposition when the substrate was blown clean using CO2 snow as it was installed into the coating chamber. In addition, the coating chamber was outfitted with a HEPA-filtered air system and maintained at a positive pressure. The clean room approach adopted by TMT should improve the cleanliness conditions, thus should improve the pinhole size and *frequency. The pinhole size and quantity affect the durability of the coating, thus should be minimized.*

[REQ-2-CO-2104] The freshly applied coatings shall cover 100% of the clear aperture and shall have combined defects within the clear aperture <0.1% of the clear aperture area. The maximum size of any one single defect shall be <5mm^2.

Discussion: Defects are defined in MIL-C-48497 Revision A and shall also include stains, streaking, smears and other coating features that would affect the spectral response of the coated surface.

Discussion: The Gemini 4-layer coating passes this inspection.

ii. Environmental, Chemical and Physical Testing

[REQ-2-CO-2200] Five (TBC) witness samples made of the same substrate material as each mirror element, and prepared in the same manner, shall be coated along with each mirror element during every coating run, under process conditions identical to the conditions existing at the mirror surface. The witness samples will be labeled.

[REQ-2-CO-2202] TBD witness samples that were coated along with the mirror element shall pass the following tests, conducted in the order presented in *Table 4*. The state of operation (defined per the ISO specification) is not applicable for all tests.

Table 4. Environmental, Chemical and Durability Testing of the Optical Coating

Description	Test Specification	Test pass criteria
Salt Mist: 5% NaCl solution at 35ºC for 2 days	ISO 9022-40-05	no reflectivity loss
Damp Heat: 16 hours at 55ºC 90%-95% relative humidity	ISO 9022-12-07	no reflectivity loss
Slow Temperature Change: 5 cycles from -10ºC to 40ºC, 2.5 hour dwell at each end, temperature change rate 0.2ºC/minute	ISO 9022-14-01	no reflectivity loss
H_2S exposure: 5 ppm at 35ºC, 75% relative humidity, for 4 days	ISO 9022-42-08	>88% reflectivity at λ≤0.5µm, no reflectivity loss at λ> 0.5µm
Coating environmental durability test for Abrasion	ISO 9211-4-01-01	No scratches discernable
Coating environmental durability test for Adhesion	ISO 9211-4-02-02	No coating removal discernable

iii. Maintainability

1. Cleaning Maintenance

[REQ-2-CO-2310] The coating on M1 segments, M2, and M3 shall be capable of being cleaned with CO_2 snow at weekly intervals over a two-year period (104 cleaning processes total).

Discussion: The proposed cleaning schedule is not dictated by throughput performance as much as by a desire to prevent dust and contaminants from adhering to the coating and reducing its lifetime per page 4 of RD10.

[REQ-2-CO-2312] The coating on TMT M1 segments M2, and M3 shall be capable of being cleaned with fluids at monthly intervals over a five-year period (60 cleaning processes total). The fluids to be used may include water, water with detergent, alcohol (methanol and ethanol), and acetone.

Discussion: The proposed cleaning schedule is not dictated by throughput performance as much as by a desire to prevent dust and contaminants from adhering to the coating and reducing its lifetime per page 4 of RD10.

[REQ-2-CO-2314] After a two year period, the total reduction in reflectivity caused by all cleanings (CO_2 snow and fluid combined) shall be less than 2%.

Discussion: Based on RD8, the Gemini coating experiences no discernible reflectivity, adhesion and durability change when exposed to the listed fluids. Figure 9 of RD11 indicates that the 4-layer Gemini coating meets this requirement.

Discussion: The reduction in reflectivity does not include the effect of dust collection over time. It is assumed that the cleaning removes the dust.

2. Recoating Maintenance

[REQ-1-OCD-2320] The interval between M2 and M3 recoating events shall be no less than 24 months (TBC), i.e. it shall be possible to meet the mean net reflectivity requirement for at least 24 months based on M2 and M3 considerations alone. During the design phase, consideration shall be given to allowing M2 and M3 recoating to be completed within the same TBC window (goal: 5 days maximum).

[REQ-2-CO-2322] The coating shall be completely strippable with chemicals within an elapsed time of no more than two hours, with no damage to the underlying substrate.

[REQ-2-CO-2324] The chemicals required to strip the coating shall not be hazardous to personnel or equipment, though protective masking, respirator, and clothing may be required.

Discussion: Materials used to strip Gemini coatings are Hydrochloric Acid and Ammonium Cerium Nitrate. Per RD8, these materials are able to strip the 4-layer Gemini coating within 30 minutes.

REQ-2-CO-2326] The M1 segment coating shall be designed so that substrate and chamber preparation and coating application can all be accomplished in less than 4 hours.

Discussion: This allows the continuous processing of M1 segments to occur within normal working hour shifts during operations, and the coating of two segments per day during Assembly, Integration and Verification.

[REQ-2-CO-2328] The coating shall be designed so that substrate and chamber preparation and coating application for the M2 and M3 can all be accomplished in less than 24 hours (three 8-hour shifts) with a goal of 16 hours.

Discussion: This allows time for careful chamber preparation, mirror cell disassembly and large mirror handling steps while leaving 2 days worth of normal working hour shifts for installation and removal of the mirrors from the telescope.

iv. Safety and Health

[REQ-1-ORD-7000] The observatory shall comply with all applicable local and national safety regulations and standards.

[REQ-2-CO-2400] The TMT coating deposition and removal processes shall not endanger the health and safety of personnel, nor cause damage to the M1 segments, M2 and M3.

[REQ-1-ORD-7200] The observatory shall comply with all applicable local and national environmental and occupational health regulations and standards.