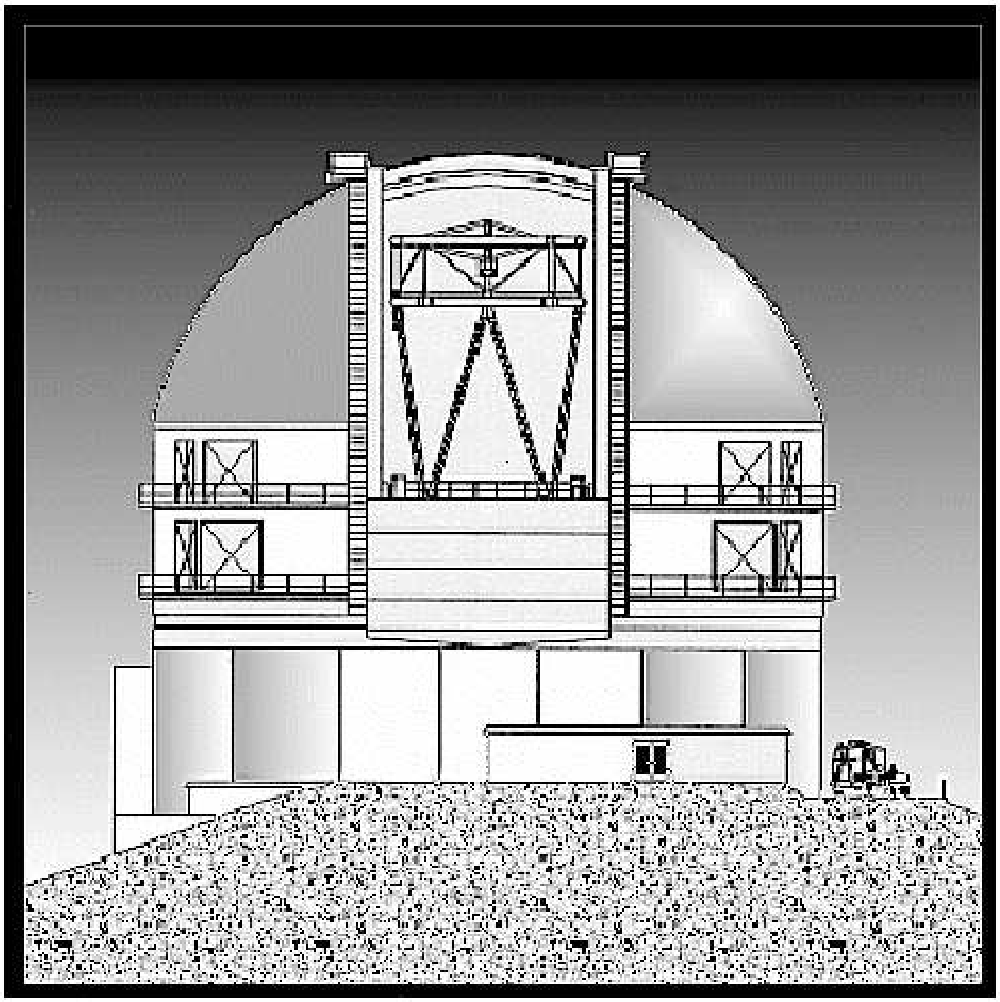
GEMINI
8-M Telescopes
Project

SPE-O-G0005

Specifications for a Generated ULE Meniscus



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December 31, 1992

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1. Definitions and Terms.

1.1 General. Capitalized terms used in the Work Scope shall have the same respective meanings given such terms in the Contract unless otherwise defined herein or unless the context requires otherwise.

1.2 Anneal. To prevent or remove objectionable residual thermal stress in a material by heating to a suitable temperature and slow, controlled cooling.

1.3 As-fired. A surface condition indicating that no grinding has been performed after the final firing. The As-fired concave surface of the Blank may exhibit a rough texture to which some small pieces of Refractory Material might adhere from the slumping form. The As-fired convex surface may contain small areas of devitrification and opaque defects from the burners.

1.4 Axial. The direction along the axis of rotational symmetry of a Boule.

1.5. Axial CTE. The Coefficient of Thermal Expansion of the ULE™, measured in the Radial direction, on a sample of glass cut from the edge of a Boule, at one of a number of locations along a line from the top of the Boule to the bottom.

1.6 Birefringence. The difference (retardation) between the path length of light propagating in the direction of maximum strain and that propagating in the transverse direction, per unit path length. A result of different indices of refraction due to inherent or imposed strains in the material.

1.7 Blister. An imperfection; specifically, a relatively large bubble or gaseous Inclusion typically non-spherical with a nearly flat dimension; in ULE™, found only in fusion seams.

1.8 Boule. A disc of ULE™ produced in one furnace by the flame hydrolysis process. The nominal usable size of Boules is 1.5 m diameter by 12.5 cm thick.

1.9 Bubble. A nearly spherical gaseous Inclusion greater than 2 mm Mean Diameter. c.f. Seed.

1.10 Check. An imperfection; specifically, a surface crack in the Blanks.

1.11 Coefficient of Thermal Expansion ("CTE"). The fractional change in length per degree of temperature change. Mathematically, $\Delta L/L_0\Delta T$.

1.12 Critical Zone. The volume of glass adjacent to the concave surface of the completed Blanks. The shape of the Critical Zone is defined in the Drawing. As illustrated in the Drawing, the Critical Zone is a uniform 10mm in thickness. The Critical Zone includes the entire concave surface of the Blanks, except for the material within the 1.26 meter diameter circular zone in **the** center of the Blanks, and the material outside the circular zone having a diameter of 8.04 meters, as measured from the center of the Blanks.

1.13. Drawing. The "Drawing" is the Gemini 8-M Telescopes Project drawing 85-GP-2000-0002, Revision C, "Blank, Generated, Meniscus Primary Mirror, ULE™," which is attached hereto and is hereby made a part of this Work Scope.

1.14 Foreign Matter. Material other than ULE™ embedded in or projecting into the Blanks.

1.15 Hex. A Stack ground into a hexagonal shape.

1.16 Inclusion. Any material or void, other than ULE™, embedded in the Blanks, including Bubbles, Seeds, Soot Spots, Stones, Foreign Matter and other opaque spots within the Blanks.

1.17 Linear Gradient. The mathematical product of the slope of the line through the measured Stack Axial CTE values, as determined from the least square method, and the Stack thickness value.

1.18 Mean Diameter. A diameter of a single, roughly spherical Inclusion calculated by averaging maximum and minimum diameters of such Inclusion.

1.19 Non-Critical Zone. That volume of glass in the Blank exclusive of the Critical Zone.

1.20 Opaque. Any non-gaseous, non-transparent Inclusion, excluding Refractory Material.

1.21 Optional Edge Drawing. The "Optional Edge Drawing," is the Gemini 8-M Telescopes Project drawing 85-GP-2000-0043, Rev. A, "Blank, Generated, Meniscus Primary Mirror, Optional Edge Configuration," which is attached hereto and is hereby made a part of this Work Scope.

1.22 Proposal; Generating Proposal. The "Proposal" is the "Proposal for Fabrication of ULE™ Telescope Primary Mirror Blanks; Gemini 8-M Telescopes Project; Request For Proposal No. 8000842," as amended, modified and supplemented, submitted by Contractor on June 17, 1992, in response to AURA Request For Proposal No. 8000842. The "Generating Proposal" is the "Proposal for Generation of Primary Mirror Blanks," as amended, modified and supplemented, submitted by Contractor and dated October 6, 1993. Except to the extent inconsistent with the requirements of this Contract or Work Scope, the Proposal and Generating Proposal are hereby made a part of this Work Scope. In the event of any conflict between the provisions of this Work Scope and the provisions of the Proposal or Generating Proposal, the provisions of this Work Scope shall govern and control completion of the Blanks.

1.23 Radial. The direction originating at the center and extending towards the outer diameter of a Boule.

1.24 Radial CTE. The Coefficient of Thermal Expansion of the ULE™, measured in the Axial direction at a number of locations along an arc from the center of the Boule to the edge of the Boule.

1.25 Refractory Material. Solid Foreign Matter, such as particles of fire brick, originating from parts of the furnace structure or from the sagging mold, which has a CTE different from that of the surrounding Glass.

1.26 Seed. A small gaseous Inclusion in the Blanks, typically spherical, and up to 2 mm in Mean Diameter. c.f. Bubble.

1.27 Soot Spot. A collection of Seeds concentrated in a localized area. A Soot Spot shall be reported as: (a) a single Inclusion having the Mean Diameter of the area affected by the Soot Spot as a whole; and (b) the Mean Diameter of the largest single Inclusion that is a part of the Soot Spot. For purposes of determining compliance with Section 2.4.2, below, each Soot Spot shall be treated as a single Inclusion having the Mean Diameter of the area affected by the Soot Spot as a whole. For purposes of determining compliance with Section 2.4.3, below, each Soot Spot shall be treated in the manner specified in such Section 2.4.3.

1.28 Stack. A number of Boules that are fusion sealed together to attain a thickness equal to or greater than the thickness of the Blanks.

1.29 Stone. An imperfection; specifically, a crystalline Inclusion in the Blanks.

1.30 Volumetric Average Radial CTE. The "Volumetric Average Radial CTE" is the weighted average of the absolute Radial CTE measurements defined by the following equation:

$$AVG_{VOL} = \frac{\sum_{0}^{14} d_i s_i}{\sum_{0}^{14} s_i}$$

where the value of the Radial CTE measurement at a position r_i from the center of the Boule is designated by d_i and s_i is the weighting coefficient proportional to the area of the zone for each particular of r_i. Fifteen (15) measurements will be taken along a radius of the Boule, ri = ro ... rl4**,** where r_0 is the Birefringence center of the Boule and r_{14} = 711.2 mm.

2. Specifications.

2.1 General. Contractor shall complete the Blanks in accordance with the provisions of the Contract and this Work Scope, which shall include, without limitation: (a) fabricating all Boules, which shall be formed of Coming ULE™ glass as specified in subparagraph 2.3.1, below, as required to fabricate the Blanks; (b) fusing all such Boules into Stacks, as required to fabricate the Blanks; (c) cutting and machining such Stacks into Hexes, as required to fabricate the Blanks; (d) placement of the Hexes, as required to fabricate the Blanks; (e) fusing the Hexes into the plano Blanks; (f) machine grinding both sides of the plano Blanks; (g) slumping the plano Blanks to net shape; (h) grinding the central hole in the Blanks; (i) machine grinding and generating all surfaces of the Blanks to meet the surface requirements specified in this Work Scope; (j) delivering the Blanks for inspection in the concave side up orientation; (k) upon acceptance of the Blanks, placing the Blanks concave side up in the shipping container to be provided by AURA; and (1) to the extent not inconsistent with the provisions of this Contract and this Work Scope, performing all other tasks described in the Proposal and Generating Proposal that are required or desirable to complete the Blanks. Subsequent to delivery of the Blanks, polishing operations will be performed by an optical finisher (other than Contractor) to reduce Surface A of the Blanks to final finished dimensions, which characterize the shape that the Blanks will have as finished mirrors for telescope use.

2.2 Dimensions. (a) The shape and dimensions of the Blanks, as completed, shall conform in all respects to the requirements set forth in the Drawing; provided, however, that in the event that the option set forth in paragraph 29(a) of this Contract is exercised by AURA, the shape and dimensions of the Blanks, as completed, shall conform in all respects to the requirements set forth in the Optional Edge Drawing.

(b) Contractor shall verify, in accordance with the provisions of paragraph 3. 1, below, that the Blanks comply with the provisions of subparagraph 2.2(a), above.

2.3 Materials.

2.3.1 Composition. The Blanks shall be composed entirely of Coming ULE™ titanium silicate low expansion material, designated by Coming code number 7971 ("ULE™ "). Unless expressly provided otherwise in this Work Scope, the properties of the ULE™ shall be as set forth by Contractor in the Proposal.

2.3.2 Coefficient of Thermal Expansion.

2.3.2.1 Entire Blank. The CTE of the material in the completed Blanks shall be $0 \pm 30 \times 10^{-9}$ per degree C over the temperature range of 5 degrees C to 35 degrees C, with a 95% confidence level.

2.3.2.2 Boules. The Volumetric Average Radial CTE of each and every Boule shall be $0 \pm 15 \times 10^{-9}$ per degree C. Within each Boule, all Radial CTE measurements shall be within $\pm 15 \times 10^{-9}$ per degree C of the Volumetric Average Radial CTE value for the Boule. Contractor shall also verify, in accordance with the provisions of paragraph 3.3, below, that the Blanks comply with the requirements of this subparagraph 2.3.2.2.

2.3.2.3 Stacks.

2.3.2.3.1 Stack Requirements. (a) The Volumetric Average Radial CTE of each and every Stack shall fall within a total range of 15×10^{-9} per degree C.

(b) The maximum variation of Radial CTE in each and every Stack shall not exceed 15×10^{-9} per degree C.

(c) The Linear Gradient of CTE in each and every individual Stack shall not exceed $15x10^{-9}$ per degree C.

2.3.2.3.2 Boule Placement Within the Stacks. (a) The Boules shall be combined into Stacks in a manner that will the Linear Gradient in each of the Stacks. In no event, however, shall the Linear Gradient of any Stack exceed $15x10^{-9}$ per degree C.

(b) Contractor shall evaluate the CTE data for each Boule, and based upon such evaluation, recommend combinations of Boules to be fused into Stacks. Contractor shall present such recommendations to AURA in writing prior to combining the Boules into Stacks. The recommendations shall include information about the CTE measurements of the Boules adequate, as determined by AURA in its sole discretion, for AURA to evaluate the Boules and Stacks and determine that the requirements specified in subparagraph 2.3.2.3.2(a), above, have been met Upon completion of its evaluation, AURA shall promptly approve or reject the recommendations of Contractor in writing. Contractor shall only fuse Boules into Stacks in the manner approved by AURA as provided in this subparagraph 2.3.2.3.2(b).

2.3.2.4 Hex Placement Within the Blanks. (a) Hexes shall be placed within the Blanks, while in the plano state, in a manner that will minimize the CTE of the material in the completed Blanks.

(b) Prior to placement of Hexes within the Blanks in the plano state, Contractor shall provide AURA with written information regarding the CTE measurements for all such Hexes. The information shall be adequate, as determined by AURA in its sole discretion, to determine the location of the Hexes in the Blanks in order to minimize the CTE of the material in the completed Blanks. Upon completion of its evaluation of such information, AURA shall promptly determine the Blanks. Upon completion of its evaluation of such inform placement of the Hexes within the Blanks and notify Contractor of such determination in writing. Contractor shall then promptly perform independent modeling to verify the effectiveness of the Hex placement proposed by AURA, and shall promptly notify AURA if its modeling results conflict with AURA's modeling results, or if Contractor determines that such placements will or may adversely affect the quality of the Blanks.

2.3.3 Stress Birefringence. In no event shall the stress birefringence in any Boule exceed 20 mn per cm of light path at any point in the Boule. Contractor shall verify, in accordance with the provisions of paragraph 3.6, below, that the Blanks comply with the requirements of this subparagraph 2.3-3.

2.4 Foreign Objects and Defects.

2.4.1 General. (a) Inclusions having a Mean Diameter less than 0.12 mm shall be exempt from the requirements of this Section 2.4. Contractor shall verify, in accordance with the provisions of paragraph 3.5. below, that the Blanks comply with the provisions of this Section 2.4.

(b) In no event shall any Inclusions located within the Blanks have cracks propagating from them that are greater than 2 cm as measured in any dimension.

2.4.2 Foreign Objects and Defects Within the Critical Zone. (a) In no event shall any Inclusion located partially or wholly within the Critical Zone exceed 5 mm in Mean Diameter. The total number of Inclusions located partially or wholly within the Critical Zone, collectively, having a Mean Diameter of between 1 mm and 5 mm, shall not exceed three (3) per any 100 cubic centimeters (e.g., any square volume 10 cm by 10 cm by 1 cm thick) of material in the Blanks. The average number of Inclusions located partially or wholly within the Critical Zone, collectively, having a Mean Diameter of between 1 mm and 5 mm, shall not exceed three tenths (0.3) per 100 cubic centimeters of material in the Blanks. In no event shall there be visible Refractory Material located partially or wholly within the Critical Zone.

(b) The fusion seams between Hexes within the Critical Zone shall be continuous and clear and shall be a minimum of 99% sealed. A fusion seam between Hexes is 99% sealed if the area occupied by Blisters and Inclusions, collectively, as measured in the plane of any fusion seam between Hexes, does not exceed 1.0% of the total area of such fusion seam.

(c) In no event shall any Blister located partially or wholly within the Critical Zone exceed 2.5 mm, as measured in its longest dimension.

2.4.3 Foreign Objects and Defects Within the Non-Critical Zone. (a) In no event shall any Inclusion located within the Non-Critical Zone exceed 10 mm in Mean Diameter; provided, however, that in no event shall the largest single Inclusion that is a part of any Soot Spot located within the Non-Critical Zone exceed 10 mm in Mean Diameter, and in no event shall the total area affected by any Soot Spot located within the Non-Critical Zone exceed 25 mm in Mean Diameter. The average number of Inclusions located within the Non-Critical Zone, collectively, having a Mean Diameter of between 1 mm and 25 mm, shall not exceed three (3) per 100 cubic centimeters of material in the Blanks. For determining compliance with the requirements of the preceding sentence, each Soot Spot shall be deemed to be a single Inclusion having a Mean Diameter of the area affected by the Soot Spot as a whole.

(b) The fusion seams between Hexes within the Non-Critical Zone shall be continuous and clear and shall be a minimum of 98% sealed. A fusion seam between Hexes is 98% sealed if the area occupied by Inclusions and Blisters, collectively, as measured in the plane of any fusion seam between Hexes, does not exceed 2.0% of the total surface area of such fusion seam.

(c) In no event shall any Blister located within the Non-Critical Zone exceed 75 mm, as measured in its longest dimension.

2.5 Annealing. (a) The stress birefringence of the Blanks resulting from permanent strain (i.e., not resulting from the gravitational loading of the Blanks or from contact forces applied to the Blanks by supporting hardware) shall not exceed 35 manometers per centimeter of light path, as measured perpendicular to the convex face of the Blanks. This requirement shall not, however, apply to the material within the 1-meter diameter circular zone in the center of the Blanks.

(b) Contractor shall verify, in accordance with the provisions of paragraph 3.6, below, that the Blanks comply with the requirements of subparagraph 2.5(a), above.

2.6 Surface Finish **and Condition.** (a) All surfaces of the Blanks shall exhibit a generated finish, with no Foreign Matter penetrating into the Critical Zone.

(b) In no event shall any visible cracks or Checks intersect any exterior surface of the completed Blanks. Contractor shall completely remove all intersecting visible cracks or Checks by localized grinding in a manner that will not damage the Blanks. Contractor shall also round-out the contours of any Blisters, Bubbles, Chips or ground-out Cracks and Checks that intersect any exterior surface of the Blanks. Subsequent to rounding the contours, the rounded-out portions shall be etched with hydrofluoric acid to blunt microscopic cracks that may have formed in the vicinity of the Blisters, Bubbles, Checks, Cracks or Chips. Contractor may propose and use alternative surface treatments to be substituted for etching with hydrofluoric acid; provided, however, that Contractor has received the prior express written approval of AURA for use of such alternative surface treatments. The provisions of this subparagraph 2.6(b) are subject to the provisions of subparagraph 2.6(c), below.

(c) Checks or Chips extending into the Critical Zone shall be ground out and etched by Contractor as described in subparagraph 2.6(b), above; provided, however, that no such ground-out location within the Critical Zone shall have an area larger than I square centimeter, as measured along the concave surface of the Blanks. In no event shall more than five (5) ground-out locations, having areas between 0.25 square centimeter and 1 square centimeter, be located within the Critical Zone.

(d) Localized grinding on the convex surface of the Blanks for purposes of removal of Foreign Matter after sagging is permissible: provided, that the Blanks shall meet all dimensional requirements of the Work Scope and that the surface area of the Blanks subjected to localized grinding has been etched with hydrofluoric acid to blunt microscopic cracks left in the surface after grinding. Contractor may propose and use alternative surface treatments to be substituted for etching with hydrofluoric acid; provided, however, that Contractor has received the prior express written approval of AURA for use of such alternative surface treatments.

2.7 Identification and Traceability. Contractor shall identify each Boule and each Stack by writing a unique identifying number on each with indelible ink. Contractor shall maintain traceability of each Boule, Stack and Hex throughout the Contract Duration. An orientation mark shall be placed and maintained on the Blanks by Contractor as a reference for Hex placement.

3 Test and Measurement Methodology

3.1 Dimensions. Contractor shall measure all of the dimensions of the Blanks necessary to verify compliance with the requirement of subparagraph 2.2(a), above, while the Blanks are in the finished state in which they will be delivered. Contractor shall measure the dimensions of the

Blanks using the methods specified in Sections 2.6.1.1, 2.6.1.2. and 2.6.1.3. of the Proposal, with the following changes and additions:

1. Vertical position readings along the convex surface shall be measured along four diametral lines extending across the entire diameter of the Blank. These lines shall be approximately equally spaced in rotation every 45 degrees around the circumference of the Blank.

2. Vertical position readings shall be taken at coincident locations, at intervals of every 25 cm along the diametral lines.

3. Measurements to determine the thickness of the Blanks shall be taken at twelve (12) equally spaced positions around the outer circumference of the Blank within 25mm (as measured along a line passing through the center of the Blank) of the outside edge of the Blank, and at equally spaced locations approximately fifty (50) cm apart along four (4) diametral lines extending across the entire diameter of the Blank, approximately equally spaced in rotation every 45 degrees around the circumference of the Blank.

4. Section 2.6.1.3. describes the use of a Pi tape to measure the average outside diameter of the Blank- An additional test or measurement is required to evaluate the circularity of the outer edge of the Blank. Contractor shall propose an appropriate measurement method, which shall require approval by AURA.

3.2. Mass and Center of Mass.

3.2.1. Total Mass. Contractor shall determine the total mass of each of the Blanks, while in the finished state in which they will be delivered. The total mass shall be measured accurately, such that the measurement error, if any, is less than ±1000 kg.

3.2.2. Center of Mass. Contractor shall determine the center of mass of each of the Blanks, while in the finished state in which they will be delivered. The location of the center of mass shall be specified in terms of three mutually orthogonal coordinate axes having, the vertex of the concave surface of the Blanks as the origin.

3.2.3. Methods. Contractor shall determine the total mass of each of the Blanks, and the location of the center of mass of each of the Blanks, using the methods described in Section 2.6.2. of the Proposal. The measurement data upon which these determinations are based shall be made available to AURA, and Contractor shall provide an estimate of the accuracy of these determinations.

3.3. Coefficient of Thermal Expansion. Contractor shall verify that all requirements of subparagraph 2.3.2, above, have been met. At a minimum, Contractor shall measure the CTE in each and every Boule and in each and every Stack using the methods described in Section 2.6.3.2 of the Proposal.

3.4. Foreign Objects and Defects. Contractor shall verify that all requirements of Section 2.4, above, have been met. At a minimum, Contractor shall make adequate (as determined by AURA in its sole discretion) measurements using the measurement techniques described in Sections 2.6.4, 2.6.5, and 2.6.6.2 of the Proposal.

3.5 Stress Birefringence. Contractor shall verify that all requirements of subparagraph 2.3.3 and paragraph 2.5, above, have been met. Contractor shall measure the Stress Birefringence in each and every Boule, each and every Stack, and in the Blanks (while in the finished state in which they will be delivered) using the methods described in Section 2.6.7 and Figure 2.6.2 of the Proposal.

3.6 Surface condition. Contractor shall verify compliance with all surface finish and surface condition requirements, using the methods described in Section 2.6.6. 1. of the Proposal.

4 Quality Assurance. (a) Except to the extent inconsistent with the requirements of the Contract and this Work Scope, Contractor shall follow all of its standard procedures for quality assurance that are applicable to the Services and the Blanks

(b) Contractor, through its Quality Assurance Department, shall certify that all measuring instruments are in compliance with Mil-Std-45662.

(c) Contractor, through its Quality Assurance Department, shall maintain a system for nonconformances. If a non-conformance occurs, Contractor shall stop all related manufacturing, and submit a specification waiver with a corrective action recommendation on the form Q506-949 for AURA approval.

(d) Contractor shall submit to AURA an Inspection Data Pack that complies with all requirements specified in this Contract, which will be in a format to be determined by AURA, in its sole discretion, but which will be similar to the proposed Data Pack set forth in Appendix A-3 of the Proposal. Contractor shall submit the completed Data Pack to AURA on or before delivery of each of the Blanks.

NOTES: UNLESS OTHERWISE SPECIFIED:

1. THE DISTANCE BETWEEN SURFACE A AND SURFACE B SHALL BE UNIFORM WITHIN 2.0 mm AS MEASURED AT THE OUTSIDE DIAMETER OF THE BLANK.
2. G = AS GENERATED SURFACE
3. SURFACE B IS A PARABOLOID OF REVOLUTION ABOUT DATUM AXIS B WITH THE FOLLOWING EQUATION:

$$Z = \frac{\frac{1}{R} \times h^2}{2}$$

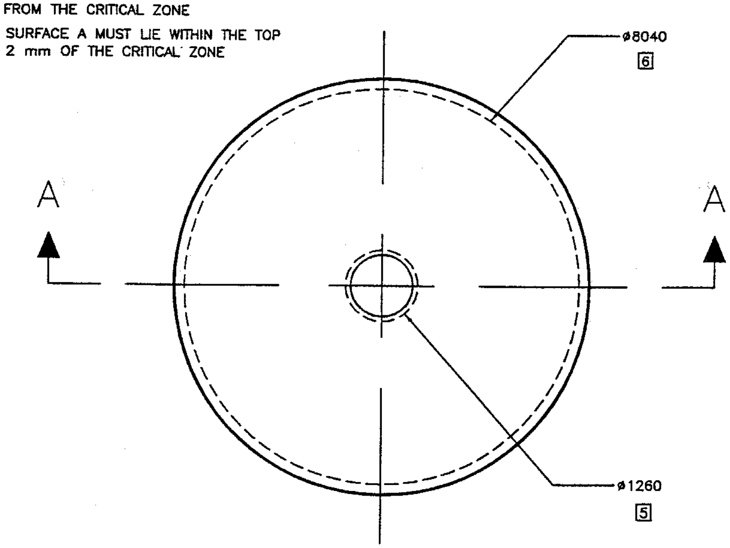
WHERE Z = SAG OF THE SURFACE PARALLEL TO DATUM AXIS B
R = 29,000
h = RADIAL DISTANCE FROM DATUM AXIS B

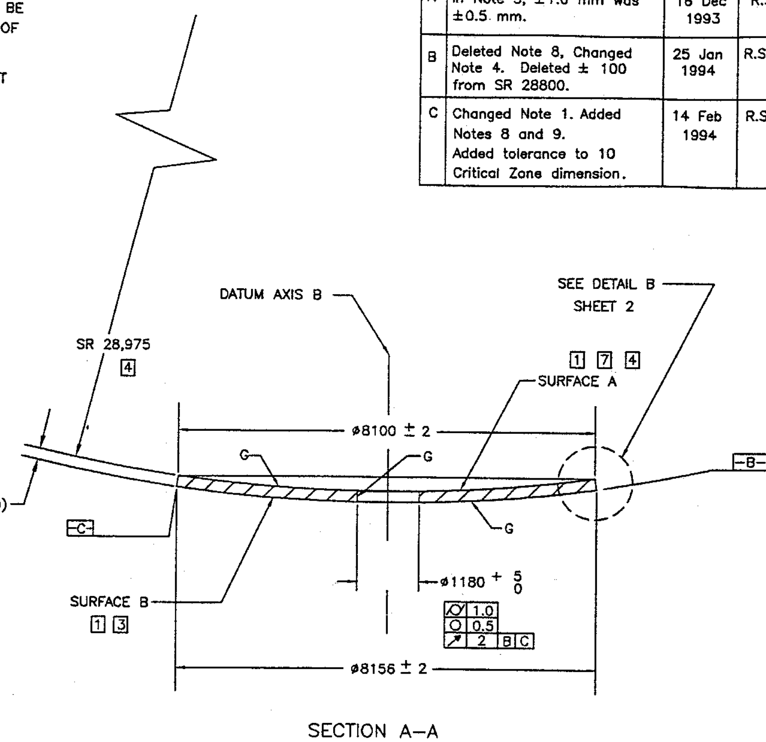
THE ACTUAL SURFACE SHALL BE WITHIN ± 1.0 mm OF THE THEORETICAL SURFACE DEFINED ABOVE.

4. SURFACE A SHALL BE WITHIN ± 1.0 mm OF THE THEORETICAL SURFACE DEFINED BY THE 28,975 mm SPHERICAL RADIUS
5. AREA WITHIN THIS DIAMETER IS EXCLUDED FROM THE CRITICAL ZONE
6. AREA OUTSIDE THIS DIAMETER IS EXCLUDED FROM THE CRITICAL ZONE
7. SURFACE A MUST LIE WITHIN THE TOP 2 mm OF THE CRITICAL ZONE
8. 200 mm DIMENSION SHALL BE MEASURED WITHIN 25 mm OF THE EDGE OF THE BLANK.
9. 45° ANGLE IS WITH RESPECT TO DATUM AXIS B.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED
A	In Note 3, ±1.0 mm was ±0.5 mm.	16 Dec 1993	R.S.Price
B	Deleted Note 8, Changed Note 4. Deleted ± 100 from SR 28800.	25 Jan 1994	R.S.Price
C	Changed Note 1. Added Notes 8 and 9. Added tolerance to 10 Critical Zone dimension.	14 Feb 1994	R.S.Price





QTY	ITEM NO.	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	PROCUREMENT SPECIFICATION	NOTES
1	1	85-GP-2000-0001	BLANK, ULE PRIMARY MIRROR		

GEMINI 8-M Telescopes Project

BLANK, GENERATED MENISCUS PRIMARY MIRROR

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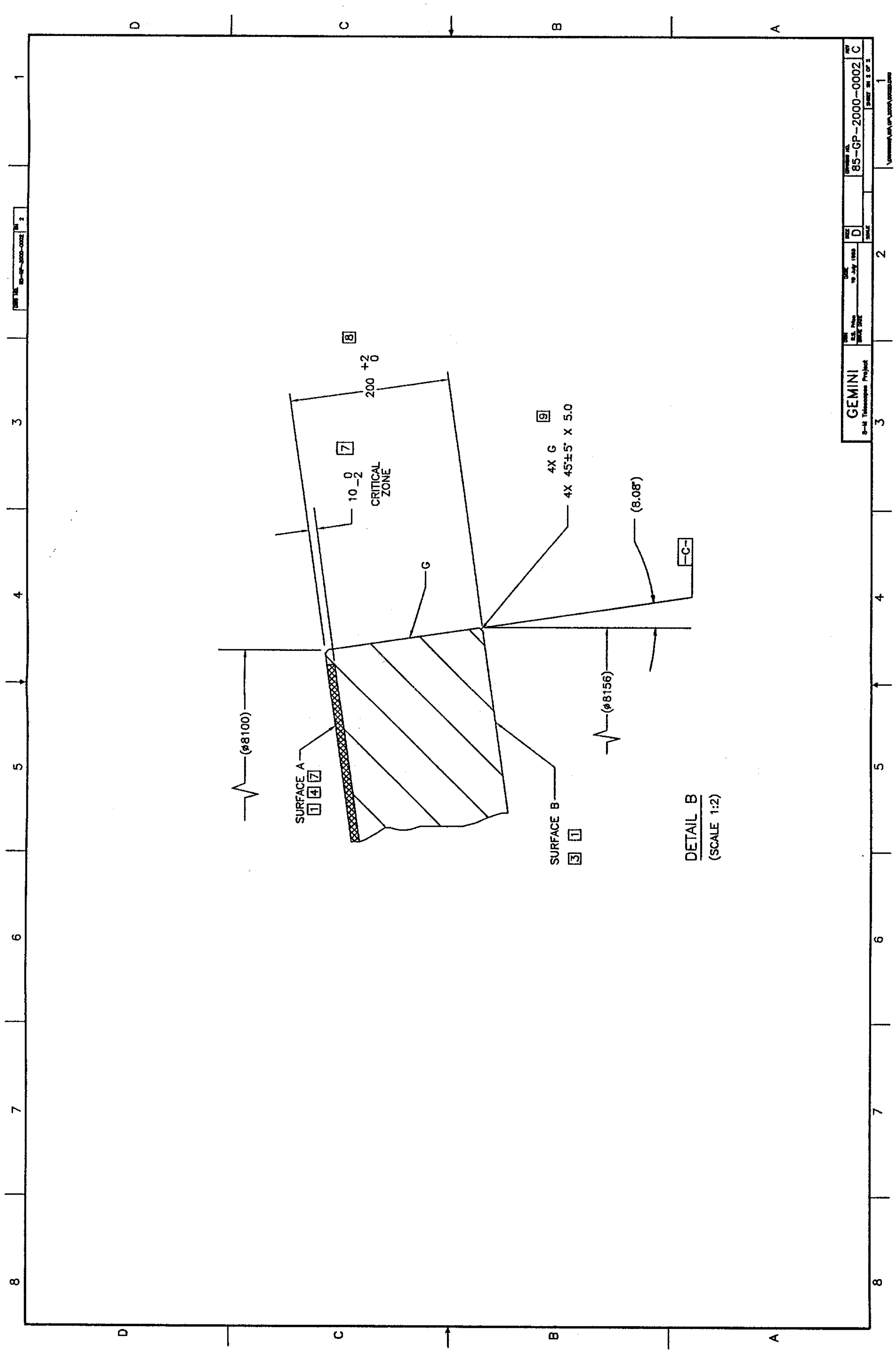
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SURFACE A
SURFACE B
CRITICAL ZONE
(ø8100)
(ø8156)
(8.08°)
4X G
4X 45°±5° X 5.0
-C-
GEMINI
85-GP-2000-0002