Manufacturing, Assembly, Integration and Testing

1. Lens and Mirror Manufacturing
2. Optical Testing
3. Alignment
4. Testing

Introduction

- Detailed design finished and reviewed
- Tolerancing
- Alignment and test plans
- Write manufacturing requirements
- Obtain quotes
- Select vendor and sign contract
- Monitor manufacturing contracts
- Test and accept/reject products

Example: VSM

- Vector-SpectroMagnetograph on Kitt Peak, USA
- 55-cm f/6.6 helium-filled solar telescope
- Compact spectrograph and polarimeter

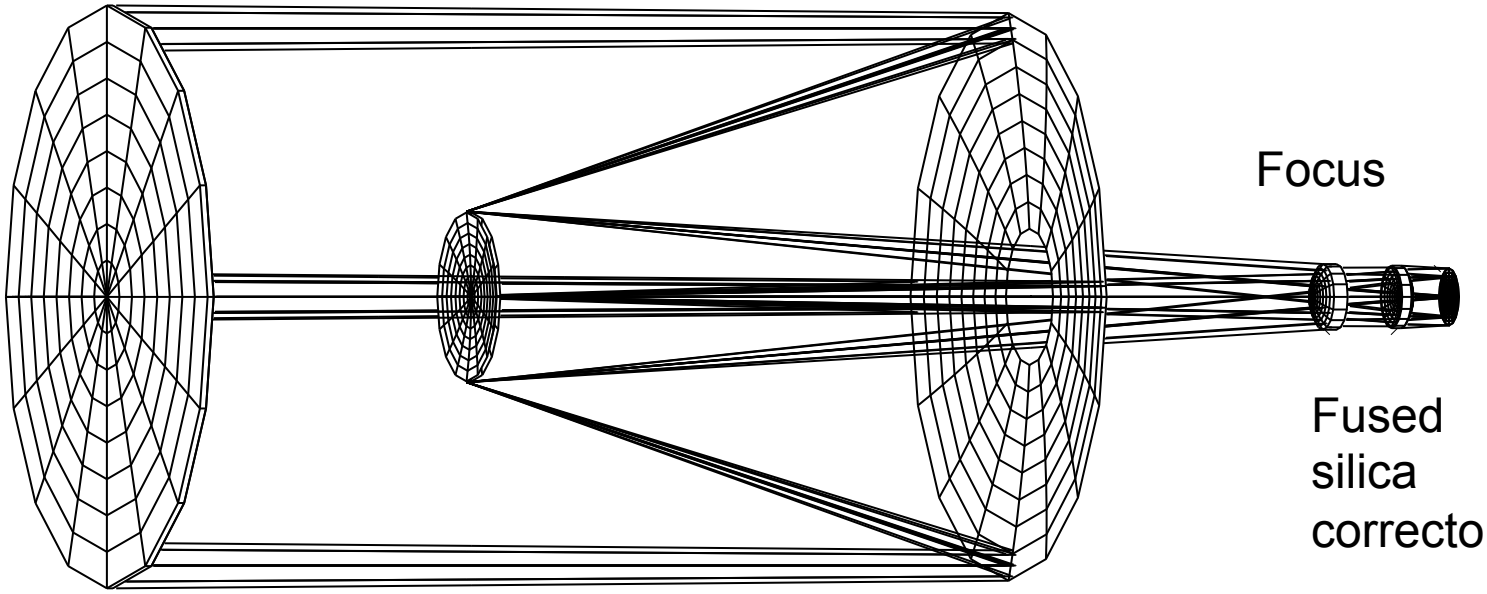
Telescope Drawing

Entrance window

Silica, ca = 544 mm, thick = 6 mm, wedge: 30’’

Primary mirror,

r = 1600 mm, cc = -1.096386, ca = 530 mm



Focus

Fused silica corrector

Secondary mirror

r = 685.9105, cc = -3.751586, ca =158 mm.

Performance with Temperature/Orientation with Gravity

Thermal coefficient of expansion of the telescope materials:

Primary mirror:	**ULE**	**≈ 0**
Secondary mirror:	**Silicon,**	**2.62 x 10^{-6}/ K**
Tube:	**Steel,**	**11.7 x 10^{-6}/ K**
Corrector:	**Fused silica**	**0.42 x 10^{-6}/ K (at 293 K)**

Temperature change mainly introduce defocus, The analysis result shows the defocus is about 0.0066 mm / C°

The temperature defocus are compensated by adjusting the separation of primary and secondary mirrors.

Temperature	0°	20°	40°
630.2 nm	548.1543 mm	548.1396 mm	548.1249 mm
854.2 nm	548.1536 mm	548.1388 mm	548.1242 mm
1083 nm	548.1532 mm	548.1384 mm	548.1238 mm

Tolerances

- How accurate does every individual element have to be made and held in place so that the whole system will fulfull the top-level requirements
- Manufacturing tolerances
- Alignment tolerances
  - During assembly (static errors)
  - During operations (dynamic errors)
- Based on error budgets

Fabrication related tolerances

Primary and secondary mirror radius and conic constant

Name	quantity	tolerance	degrade of whole system	
Primary radius	1600	2	.0015	
Primary CC	-1.096386	0.002	.0097	
Secondary radius	-685.9104 685	1	.0175	
Secondary CC	-3.751586 36	0.002	.0011	

Corrector radius, thickness and TIR

Lens 1, radius 1	50.9747	0.02	.0148	
Lens 1, radius 2	40.373	0.02	.0039	
Lens 2, radius 1	-55.49255	0.02	.0058	
Lens 2, radius 2	-50.3909	0.02	.0093	
Lens 1, thickness	13	0.02	.0010	
Lens 2, thickness	11	0.02	.0022	
Lens 1, TIR	62	.0100	.0011	0.012806248
	62	.0080	.0048	
Lens 2, TIR	60	.0100	.0048	0.014142136
	60	.0100	.0103	
		subtotal	.0303	

System allignment related tolerance

Separation			
Primary to corrector	275.75204	0.1	-.0006
Lens separation	71.902176	0.05	.0280
Corrector to slit	38	0.4	.0020
Secondary mirror, decenter and tilt			
Decenter		0.01	.1071
Tilt		5.0"	.0978
Corrector lens, decenter and tilt			
lens 1, decenter	decenter	0.02	.0354
lens 2, decenter	decenter	0.02	.0246
lens 1, tilt	tilt	60.0"	.0070
lens 2, tilt	tilt	60.0"	.0011
corrector decenter and tilt			
corrector decenter	decenter	0.1	.0042
Corrector tilt	tilt	120.0"	.0021
	subtotal		.1541
Total system degradation			.1571

Alignment Tolerances

	x		y		z		rot x		rot y		rot z	
	μm	mil	μm	mil	μm	mil	deg	arcsec	deg	arcsec	deg	arcsec
primary mirror	10	0.39370 0787	10	0.39370 0787			0.001	3.6	0.001	3.6		
secondary mirror	10	0.39370 0787	10	0.39370 0787			0.0015	5.4	0.0015	5.4		
corrector assembly	100	3.93700 7874	100	3.93700 7874	100	3.93700 7874	0.1	360	0.1	360		
corrector lens 1	25	0.98425 1969	25	0.98425 1969	50	1.96850 3937	0.03	108	0.03	108		
lens 1 thickness					20	0.78740 1575						
corrector lens 2	25	0.98425 1969	25	0.98425 1969	50	1.96850 3937	0.1	360	0.1	360		
lens 2 thickness					50	1.96850 3937						
corrector spacing					50	1.96850 3937						

Requirements/Specifications

- Material
- Mechanical dimensions
- Optical properties
  - Clear aperture
  - Radius of curvature
  - Conic constant
  - Thickness
- Test procedures
- Deliverables

Material Requirements Example: VSM M1

SOLIS will provide the primary mirror blank. The plano / plano mirror grade Corning ULE 7972 blank is 22.663 inches diameter x 2.988 inches thick. (575.64 mm diameter x 75.90 mm thick).

Typical mirror materials:

- Schott Zerodur
- Corning ULE
- Astrosital
- SiC, Be

Mechanical Dimensions Example: VSM M1

Finished Dimensions

Outer diameter	575.00 m+/-1.0mm
Edge thickness	75.00 mm +/-1.0mm
Central hole diameter	126.62 mm+/-1.0mm
Central hole concentricity with outside diameter	<0.5 mm
Flatness of back surface (overall)	<0.025 mm
Flatness of back surface (local)	< 4 fringes over 4 inch diameter test plate
Edge bevels	45º x 4.8 mm

Optical Specifications Example: VSM M1

Clear Aperture

Clear aperture outside diameter	20.9 inches	(530 mm)
Clear aperture inside diameter	5.8 inches	(147 mm)

Surface Finish

Concave optical surface	pitch polished to 60-40 scratch dig or better
Back surface, sides, bevels	commercial polished

Radius of Curvature

Paraxial radius of curvature	62.992 inches +/- 0.080	(1600 mm +/- 2.0 mm)

Conic Constant

The surface is a concave hyperboloid with a conic constant of -1.096386 +/- 0.002.

Surface Figure

The overall surface figure will be measured interferometrically and will be 25 nm RMS or better. The diffraction spot size will be such that 80% of the reflected light at .633 um will be contained within a spot size of 0.8 arc-sec. diameter.

Surface Micro-roughness

The optical surface micro-roughness shall be 2 nm rms or better and shall be measured at no fewer than three equally spaced radial zones and three equally spaced azimuths.

Opto-Mechanical Specifications Example: VSM M1

Optical Testing Support

Testing of the primary mirror will be done with the mirror supported at the same locations as used in the telescope cell. A suitable etched fiducial mark will be made on the edge of mirror so as to orient it in azimuth to the mirror cell. The locations of the support points are indicated on the attached print. Final acceptance testing will be done with the mirror zenith pointing using the telescope mirror mounts supplied by SOLIS.

Mechanical / Optical Axes

The optical center should be decentered no more than 0.5 mm from the mechanical center as defined by the outside diameter of the mirror. The mechanical axis is defined as passing through the mechanical center of the mirror perpendicular to the back surface of the mirror. The optical axis shall be tilted no more than 20 arc-sec. from the mechanical axis. This is equivalent to a wedge of 0.001” (0.002” TIR) measured at the outside diameter.

Deliverables Example: VSM M1

- The deliverables under this contract shall be the Primary Mirror and a final report containing the Contractor's measurements, test data demonstrating compliance with the specifications including, but not limited to,

a) description of test procedures,

b) raw data,

c) test equipment calibration,

d) description of reduction procedure, and

e) reduced data.

NOTES: UNLESS OTHERWISE NOTED.

1.REMOVE ALL BURRS AND SHARP EDGES

~~2.MACHINED SURFACE ROUGHNESS~~ 125

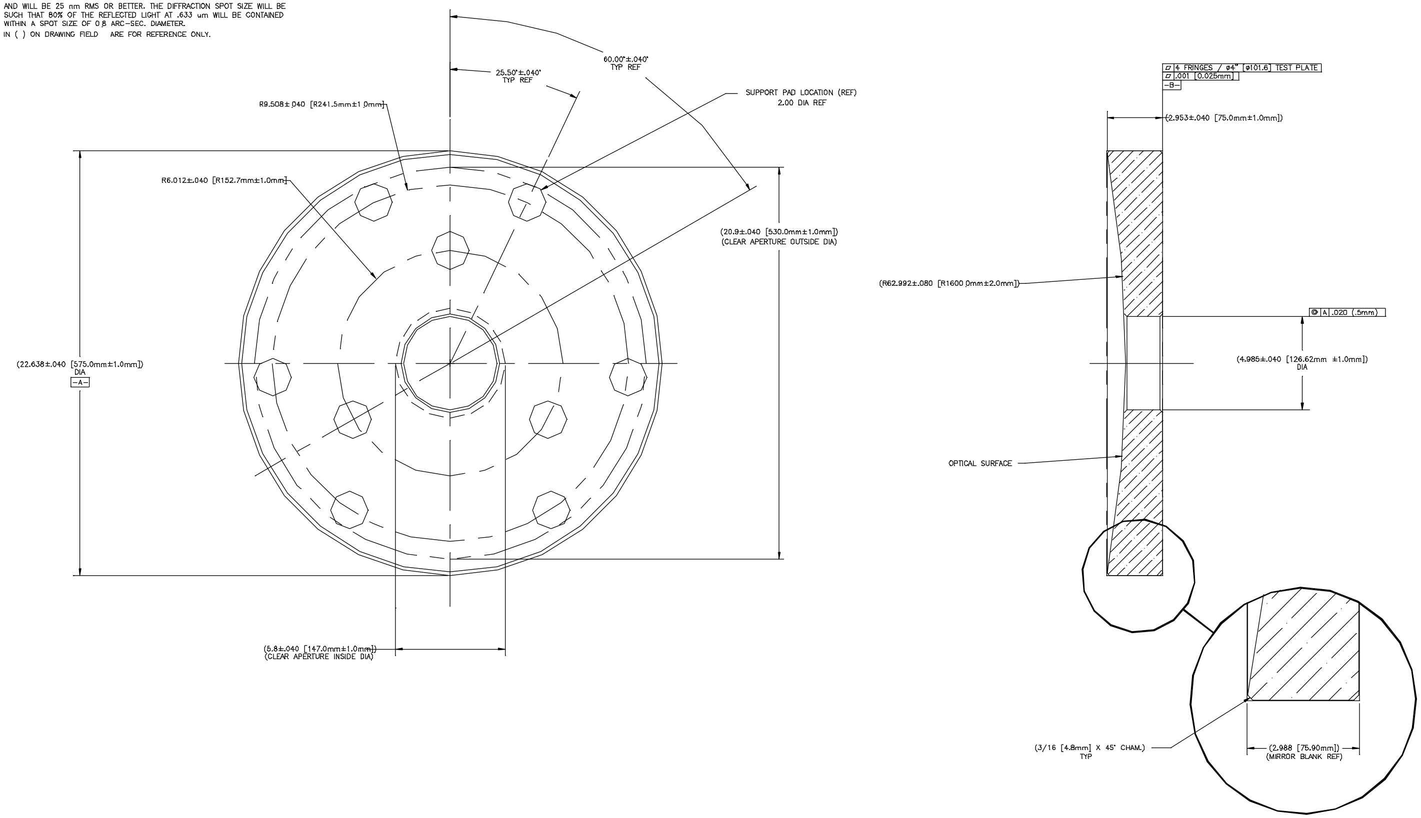
3. MATERIAL: THE PLANO / PLANO MIRROR GRADE CORNING ULE 7972
MIRROR BLANK IS 22.663 DIA. X 2.988 THK. (575.64mm DIA. X 75.90mm THK.)

4. FINISHED DIMENSIONS: (DIMENSIONS ARE IN INCHES AND MILLIMETERS)
- OUTSIDE DIA.---------- 22.638 ±.040 (575.0mm ± 1.0mm)
- EDGE THICKNESS---------- 2.953 ± .040 (75.0mm ± 1.0mm)
- CENTRAL HOLE DIA.---------- 4.985 ± .040 (126.62mm ± 1.0mm)
- CENTRAL HOLE CONCENTRICITY WITH OD.---------- .020 (.5mm)
- EDGE BEVELS--------- 3/16 X 45° (4.8mm X 45°)
- PARAXIAL RADIUS OF CURVATURE--------------62.992 ± .080 (1600.0mm ± 2.0mm)
- CLEAR APERTURE, OUTSIDE DIA.----------20.9 ±.040 (530.0mm ±1.0mm)
- CLEAR APERTURE, INSIDE DIA.----------5.8 ±.040 (147.0mm± 1.0mm)
- CONIC CONSTANT---------CONCAVE HYPERBOLOID WITH A CC OF −1.096386 ±.002
- OPTICAL AND MECHANICAL AXIS CENTERED TO WITHIN .019 (.50mm) RELATIVE TO OUTSIDE DIA.
- OPTICAL AXIS PERPENDICULAR TO DATUM −B−, <.0056° (<20 ARC− SEC.)

5. SURFACE FINISH:
CONCAVE OPTICAL SURFACE--------- PITCH POLISHED TO 60−40 SCRATCH DIG OR BETTER.
BACK SURFACE, SIDES AND BEVELS --------- COMMERCIAL POLISHED
THE OPTICAL SURFACE MICRO−ROUGHNESS SHALL BE 2 nm RMS OR BETTER AND WILL BE MEASURED AT NO FEWER THAN THREE EQUALLY SPACED RADIAL ZONES AND THREE EQUALLY SPACED AZIMUTHS.

6. OPTICAL SURFACE FIGURE:
THE OPTICAL SURFACE FIGURE WILL BE MEASURED INTERFEROMETRICALLY AND WILL BE 25 nm RMS OR BETTER. THE DIFFRACTION SPOT SIZE WILL BE SUCH THAT 80% OF THE REFLECTED LIGHT AT .633 um WILL BE CONTAINED WITHIN A SPOT SIZE OF 0.8 ARC−SEC. DIAMETER.

7. DIMENSIONS IN ( ) ON DRAWING FIELD ARE FOR REFERENCE ONLY.



REVISIONS					
ZONE	LTR	REVISIONS	ECR	DATE	BY APRV

USED ON SOLIS VSM		
TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMALS .XX±.01 .XXX±.005 .XXXX±.0005 FRACTIONS ±1/64 ANGULAR ±0°30'	*NATIONAL SOLAR OBSERVATORY* OPERATED BY THE ASSOCIATION OF UNIVERSITIES FOR RESEARCH IN ASTRONOMY, INC. UNDER COOPERATIVE AGREEMENT WITH ***NATIONAL SCIENCE FOUNDATION***	
NEXT ASSEMBLY SLS.2518.1005.A	NAME DETAIL— PRIMARY MIRROR	
SCALE 1/2	DESIGNED BY G. DUFFEK DATE 6/23/99 / APPROVED BY DATE	DWG. NO. SLS.2505.2010.A
PRINT ISSUED	DRAWN BY G. DUFFEK DATE 6/23/99 / APPROVED BY DATE	
DRAWING PRODUCED BY AUTOCAD VER. 14	CHECKED BY DATE / APPROVED BY DATE	RELEASE DATE / SHEET 1 OF 1

DWG NO.	SHT	REV
SLS.2505.2035	1	A

REVISIONS

REV	ZONE	DESCRIPTION	ECR	DATE	BY	APPROVED
A		INITIAL RELEASE		10/19/99	GP	

NOTES, UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS IN INCHES UNLESS OTHERWISE SPECIFIED
2. MATERIAL: FUSED SILICA
   INCLUSIONS: NONE OVER 100um, TOTAL CROSS SECTION < .03 mm2/100 cc
   STRAIN BIREFRINGENCE: < 5 nm/cm
   STRIAE: GRADE A PER MIL-G-174A
   HOMOGENEITY: ΔN < 2x10E-6 @ 633 nm
   BLANK SIZE 3.08 DIA. x 1.11 THK.
3. FINISH: SURFS A & B: POLISH TO 60/40 S/D
   SURF C: GRIND TO 12μ
   ALL OTHERS: NO REQUIREMENT
4. SURFACE IRREGULARITY: 1/2 P-V @ 633nm OVER TEST DIA.

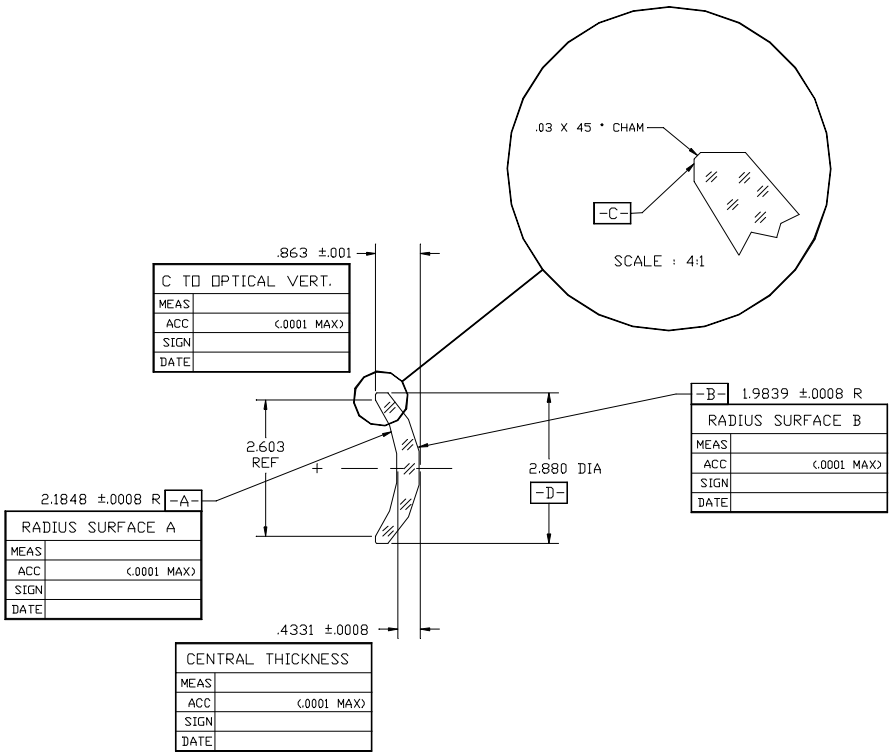
SURF A: TEST DIA: 2.17	
IRREG. SURFACE A	
MEAS	@ nm
ACC	(1/8 MAX)
SIGN	
DATE	

SURF B: TEST DIA: 2.29	
IRREG. SURFACE B	
MEAS	@ nm
ACC	(1/8 MAX)
SIGN	
DATE	

   PROVIDE INTERFEROGRAMS OF SURF A & B AND TEST PLATE FIT TO SURF B
5. WEDGE: TIR SURF C WRT SURFACES A & B < .0004

TIR SURFACE C	
MEAS	
ACC	(.0001 MAX)
SIGN	
DATE	

6. A/R COAT SURFS A&B w/ LOW-REFLECTANCE BROAD-BAND COATING
   MAXIMUM REFLECTION PER SURFACE: 1%
   WAVELENGTHS: 630nm, 854nm, 1083nm
   POLARIZATION Rs-Rp < 0.1% FROM 0 TO 30 DEG. AT 630nm



C TO OPTICAL VERT.	
MEAS	
ACC	(.0001 MAX)
SIGN	
DATE	

RADIUS SURFACE A	
MEAS	
ACC	(.0001 MAX)
SIGN	
DATE	

RADIUS SURFACE B	
MEAS	
ACC	(.0001 MAX)
SIGN	
DATE	

CENTRAL THICKNESS	
MEAS	
ACC	(.0001 MAX)
SIGN	
DATE	

ITEM NO.	QTY REQD	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	NOTES

PARTS LIST

TOLERANCES UNLESS OTHERWISE SPECIFIED
DECIMALS .XX±.01 .XXX±.005 .XXXX±.0005
FRACTIONS ±1/64
ANGULAR ±0°30'

NEXT ASSEMBLY: SLS.2526.1005

USED ON: SOLIS VSM

DWG SIZE: D | REVISION: A

SCALE: 1/1

PRINT ISSUE DATE:

DRAWING PRODUCED IN AUTOCAD VERSION 14

NATIONAL SOLAR OBSERVATORY

OPERATED BY THE ASSOCIATION OF UNIVERSITIES FOR RESEARCH IN ASTRONOMY, INC. UNDER COOPERATIVE AGREEMENT WITH *NATIONAL SCIENCE FOUNDATION*

TITLE: CORRECTOR LENS (L2)

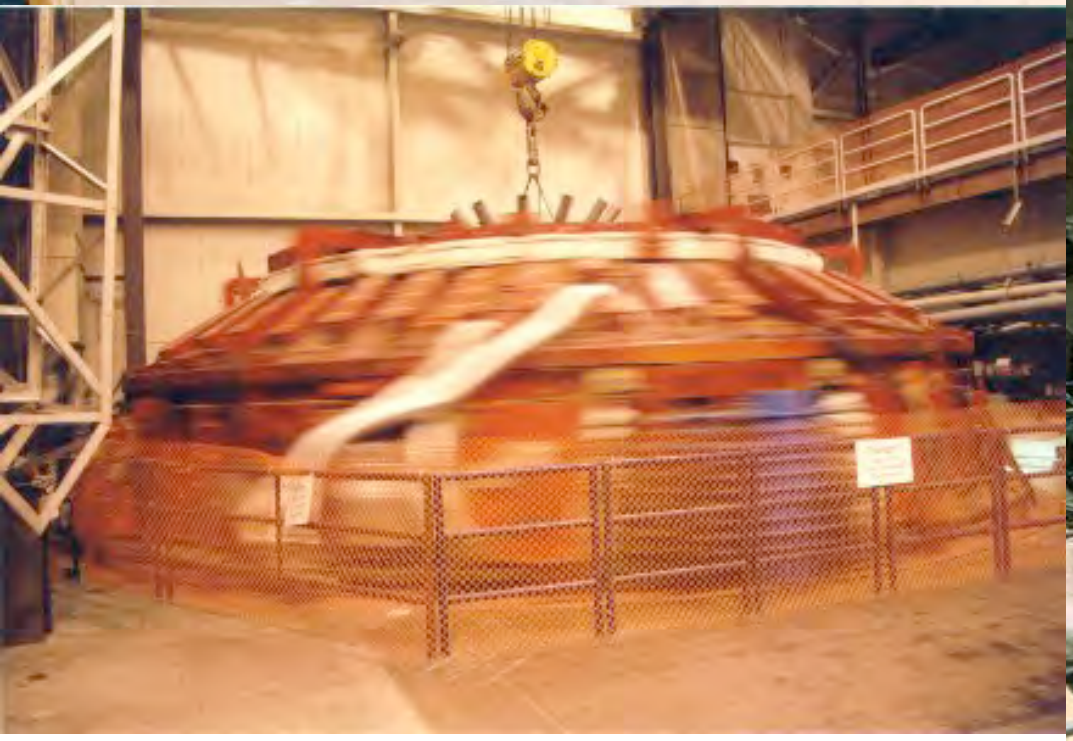
	NAME	DATE	APPROVAL	DATE
DESIGNED	M. LIANG	10/19/99		
DRAFTED	G. POCCIALP	10/19/99		
CHECKED				

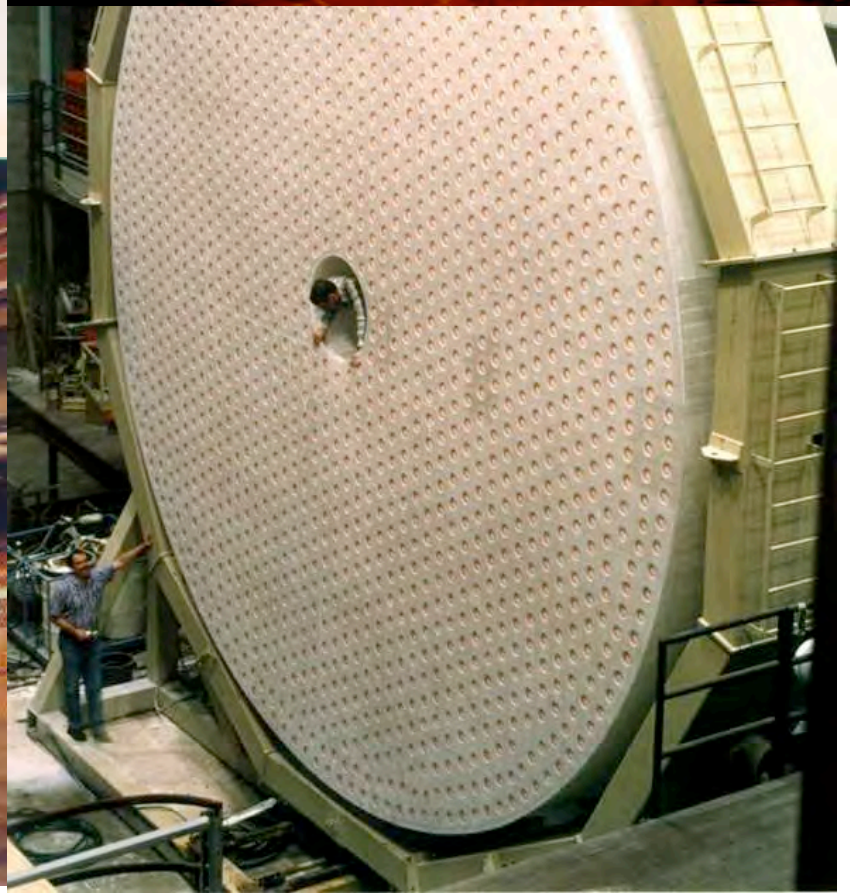
DWG NO. SLS.2505.2035

RELEASED 10/19/99 SHEET 1 OF 1

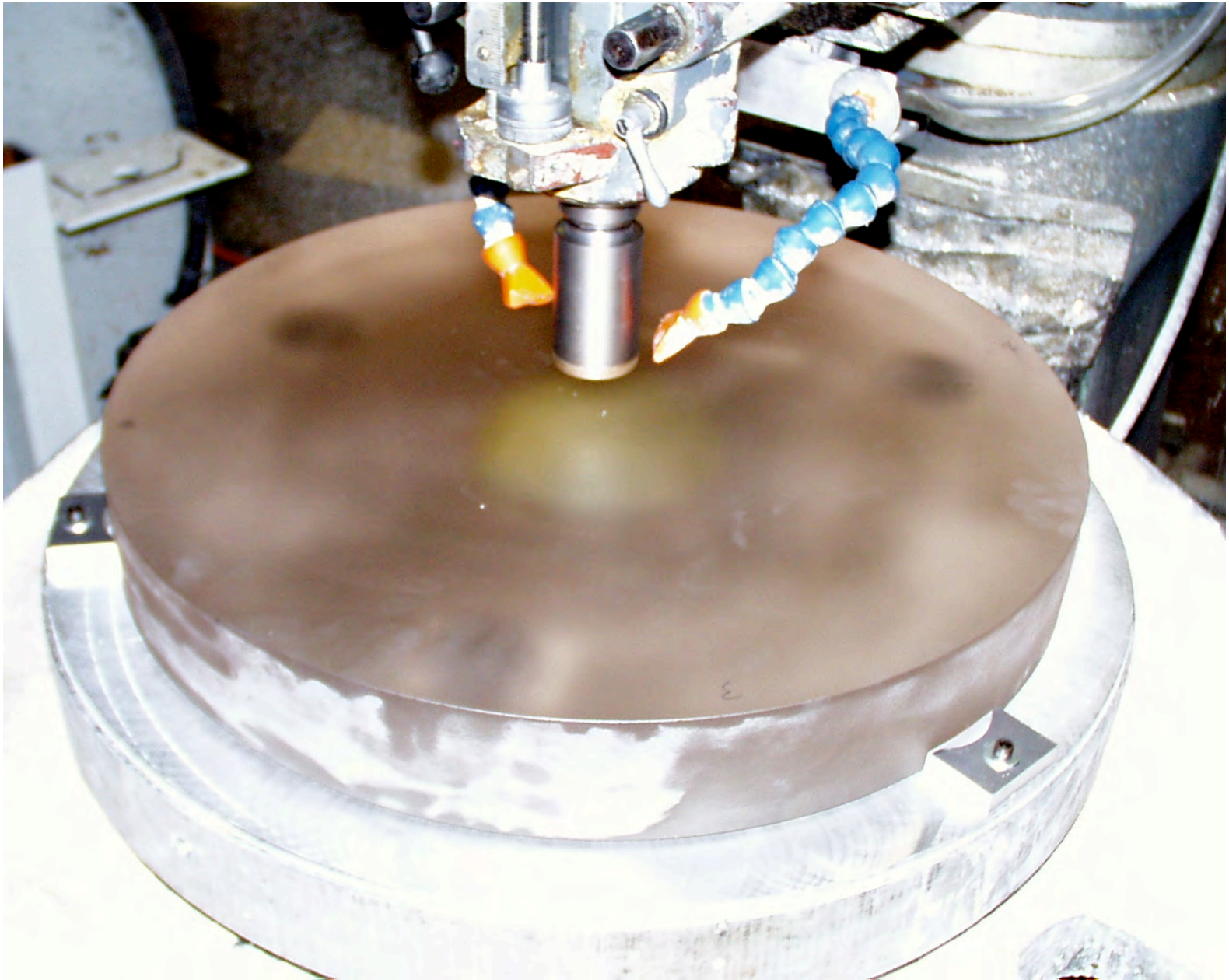
Lens and Mirror Manufacturing

- Blank manufacturing
- Surface generation
- Grinding
- Polishing

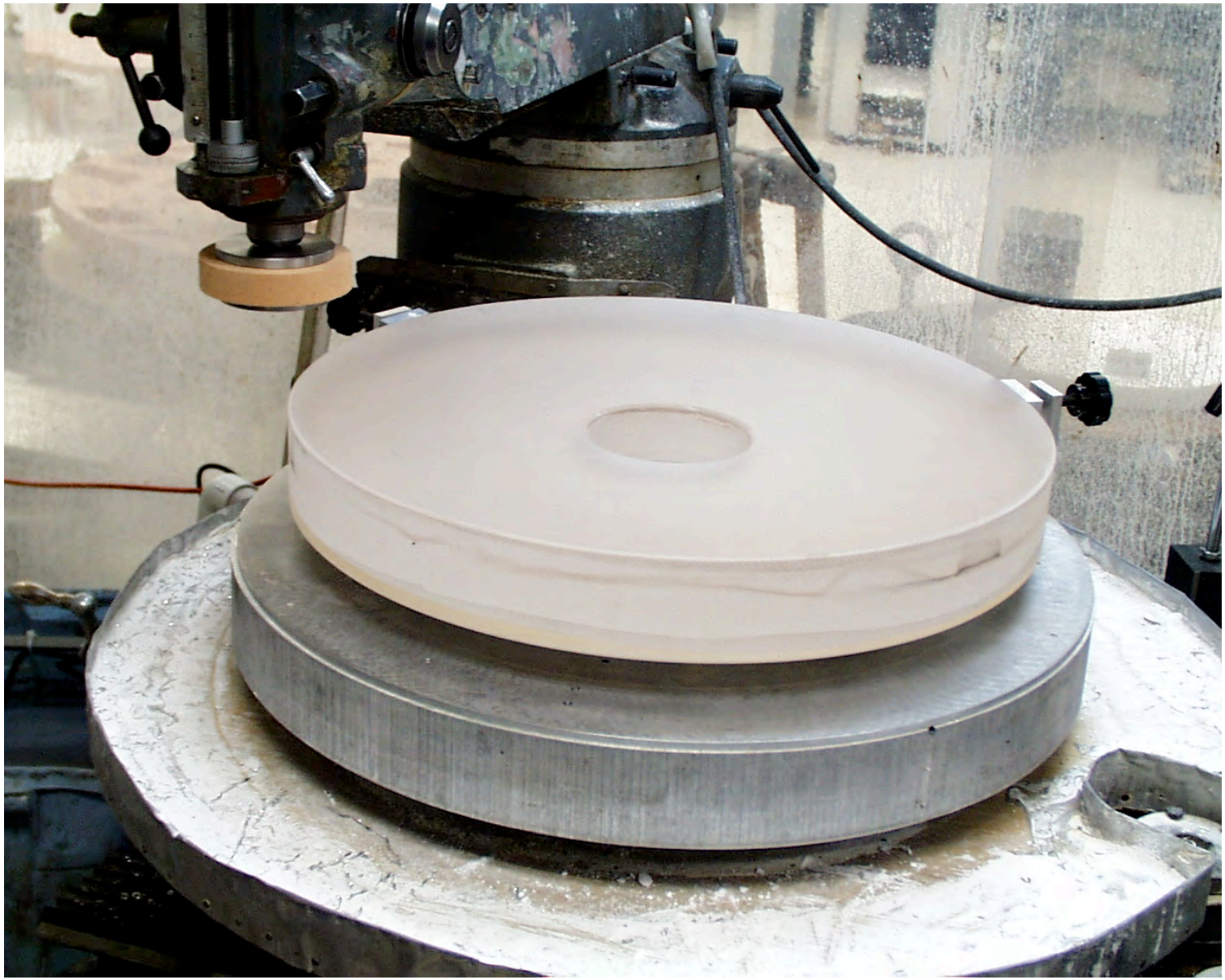




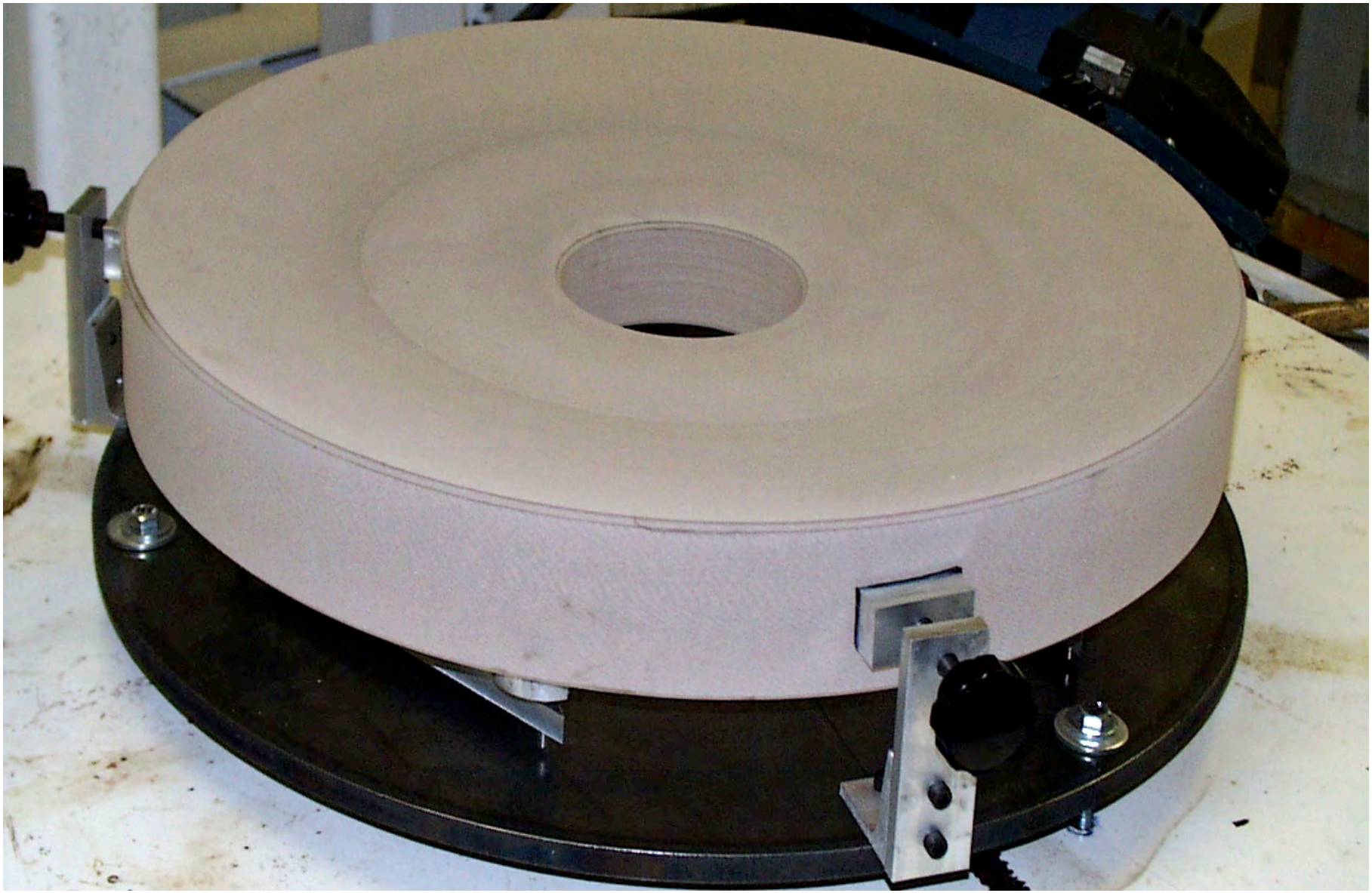
Central Hole Cutting



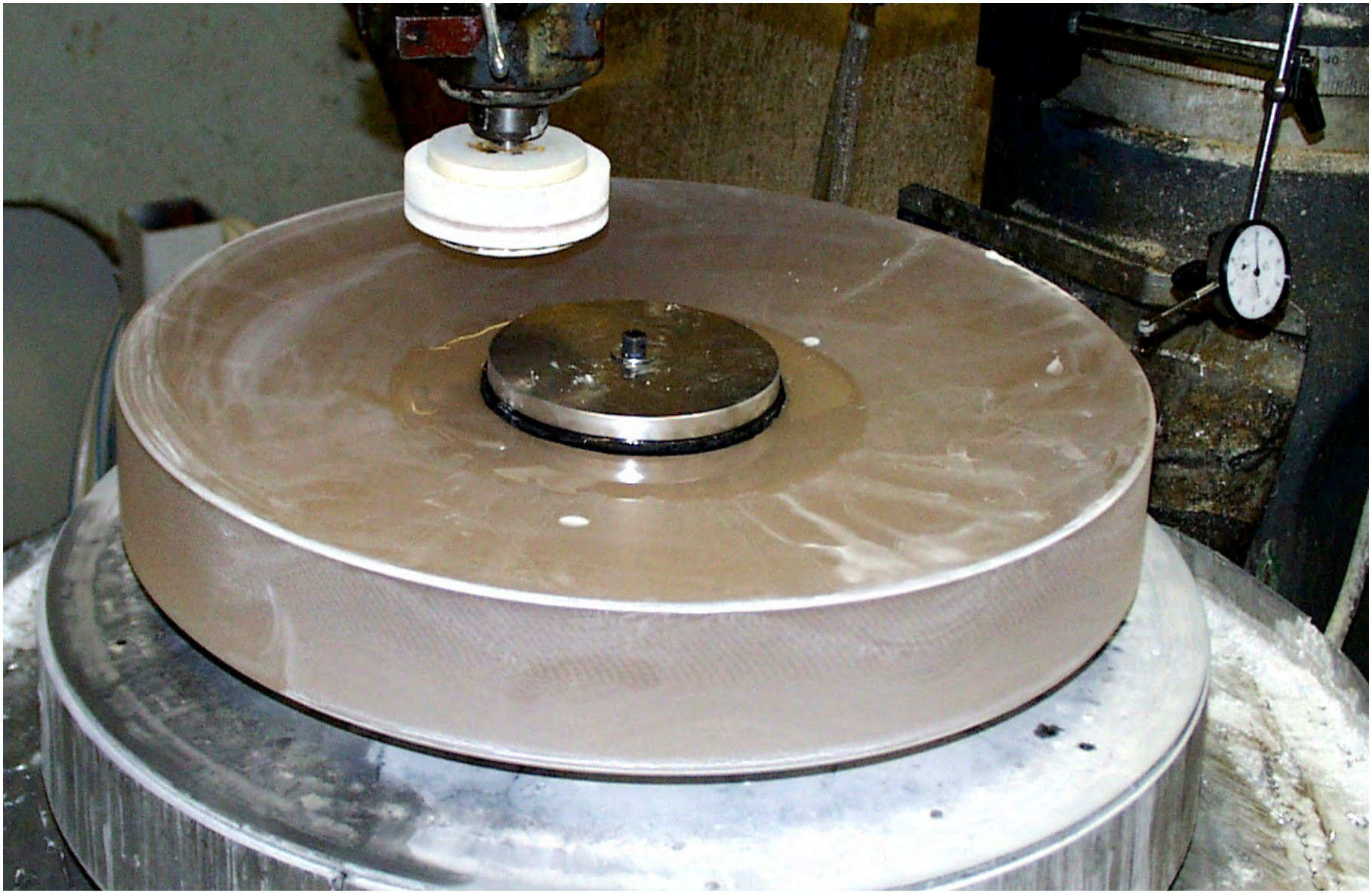
Surface Generation



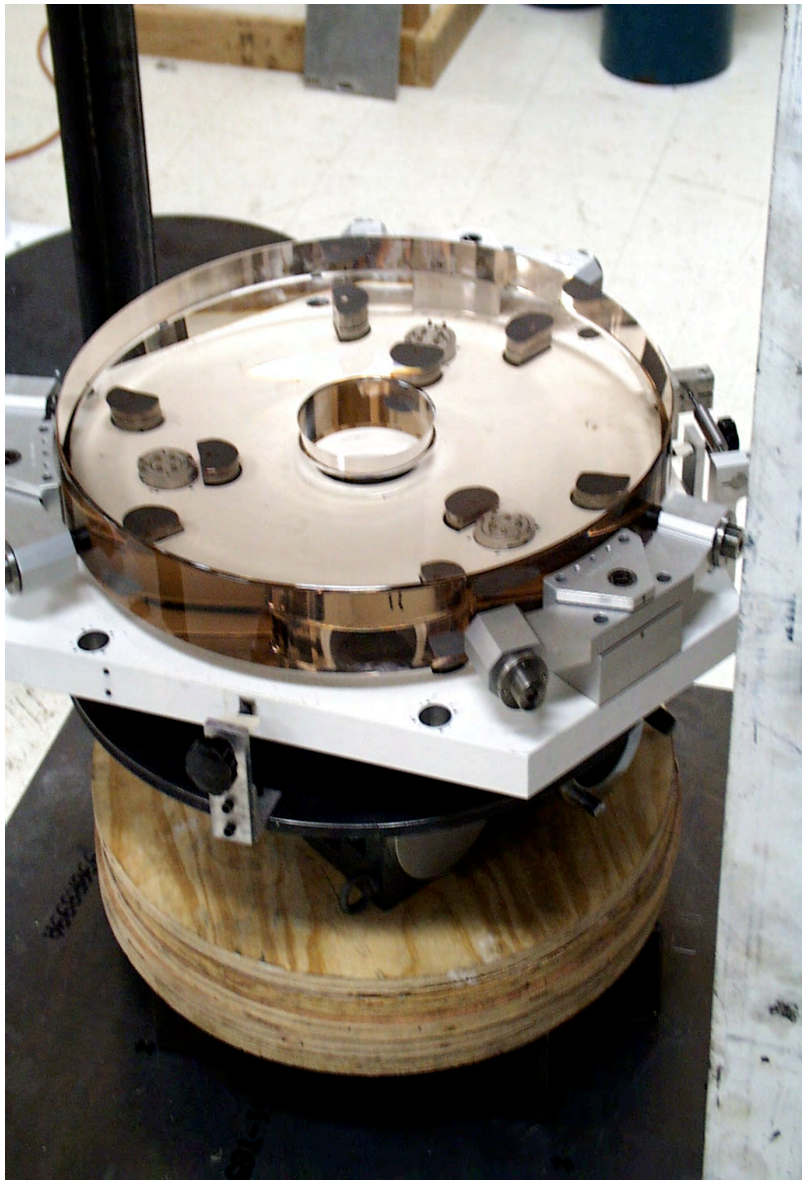
Ready for Grinding



Polishing



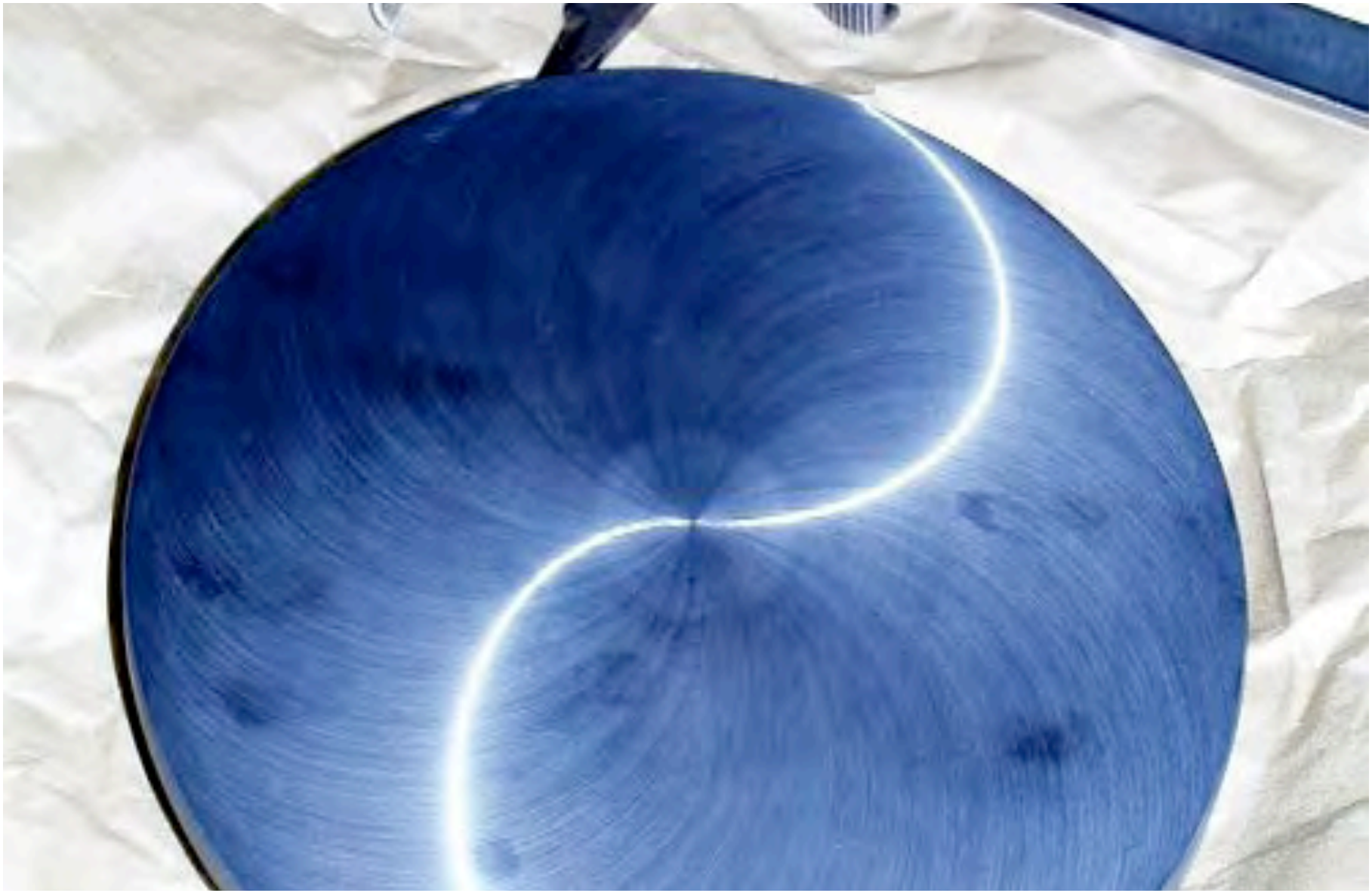
Finished Mirror Polished on all Sides



Coated Mirror Inspection

Silicon Single-Crystal VSM M2 Blank

After Grinding



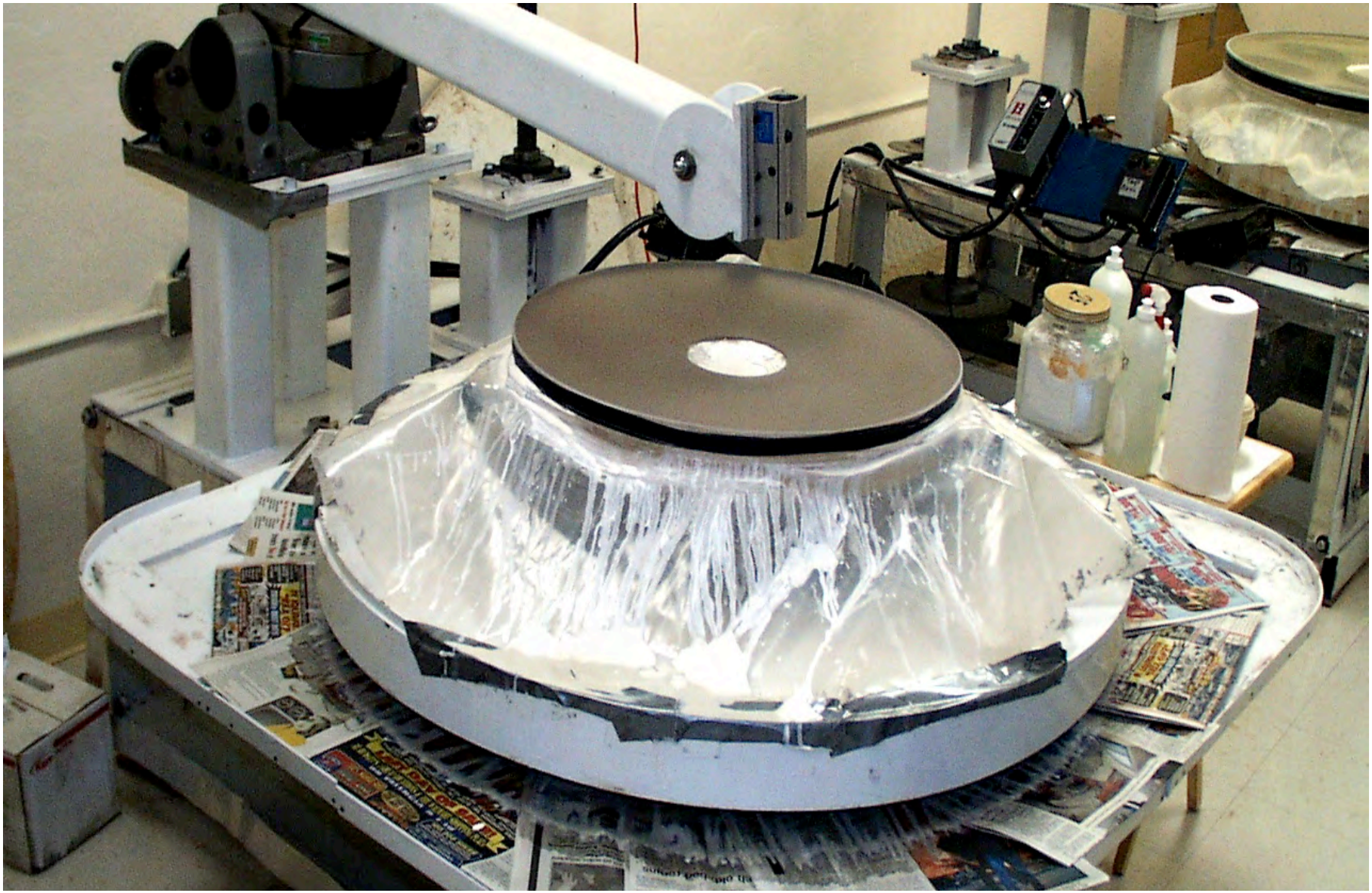
Polishing

Finished VSM
M2

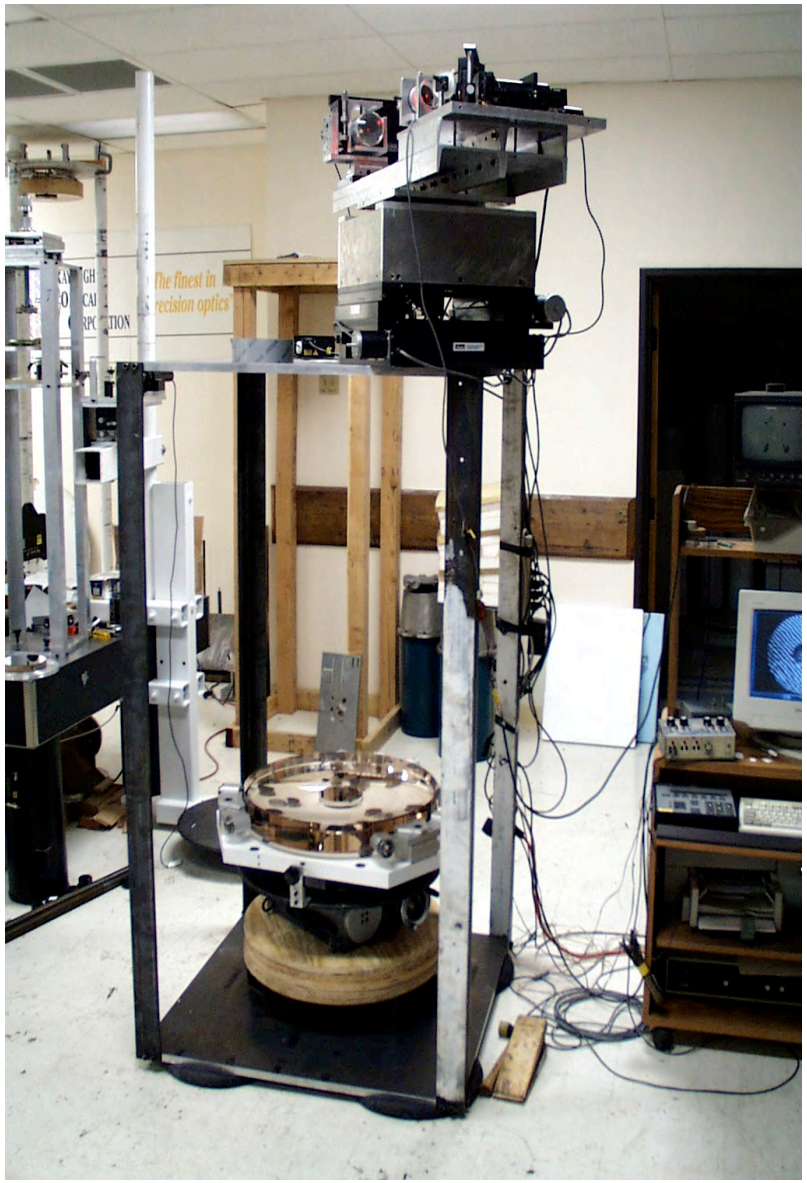
Optical Testing

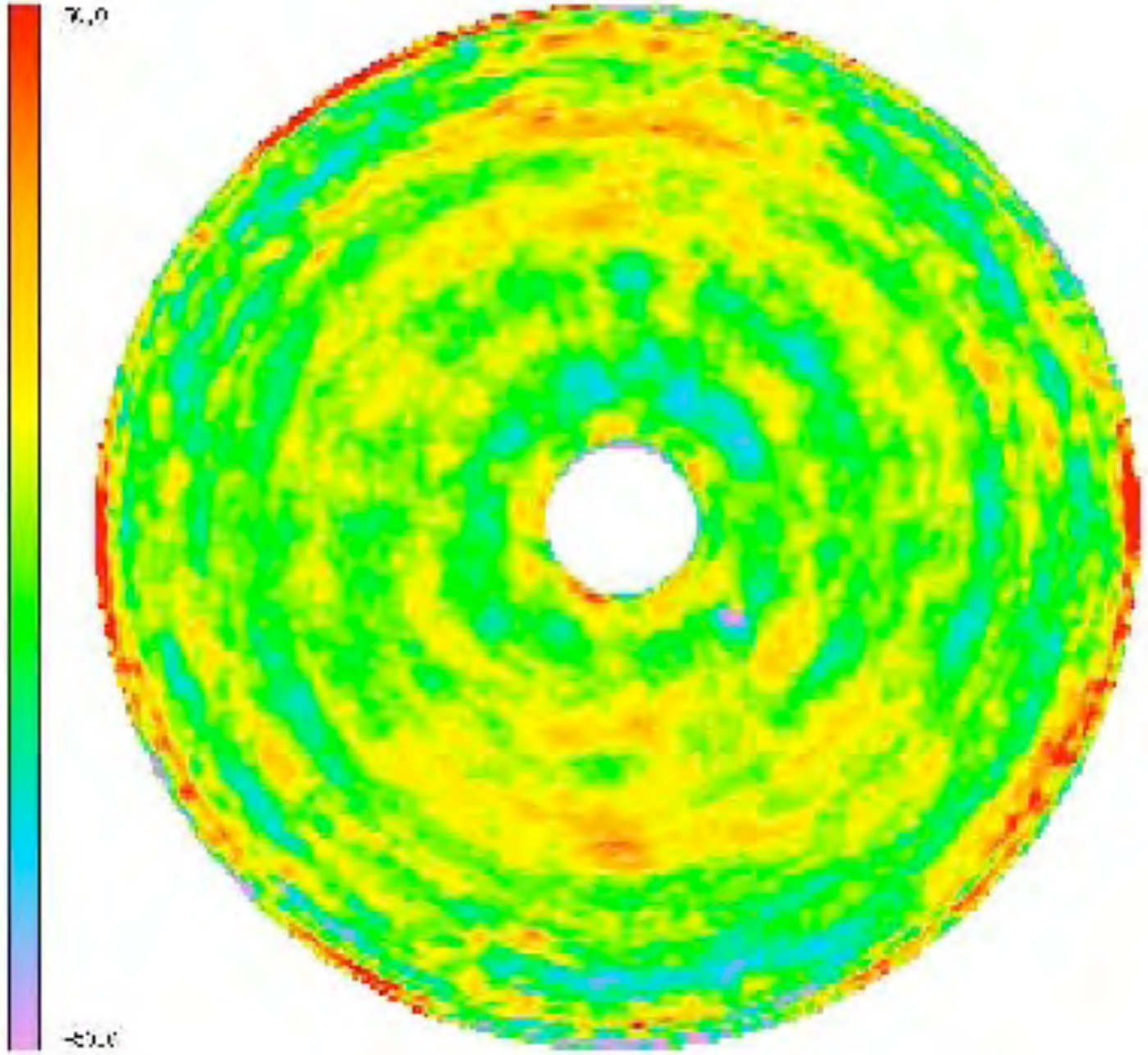
- Interferometry
- Null-lenses
- Computer-Generated Holograms

Swing-Arm Profilometer

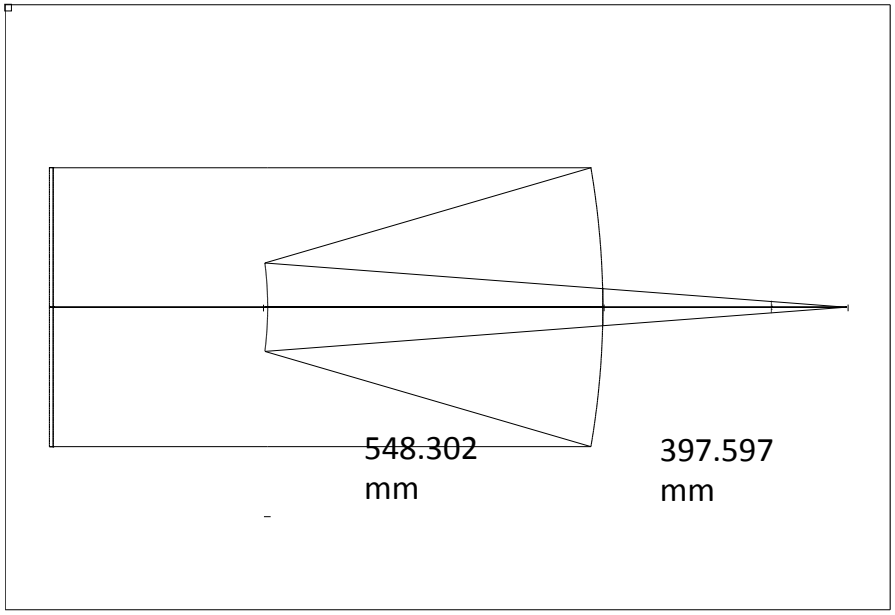


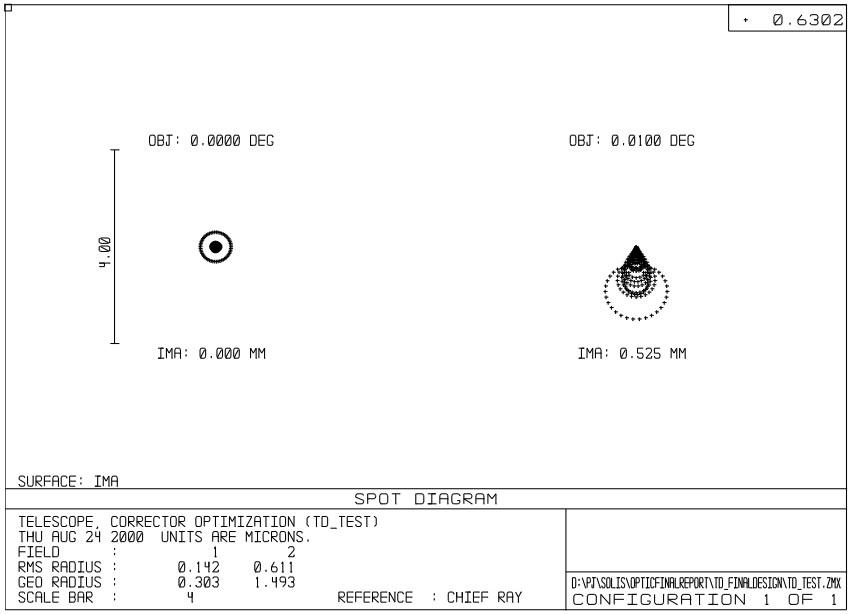
Interferometric Testing





Primary and secondary mirrors combination testing





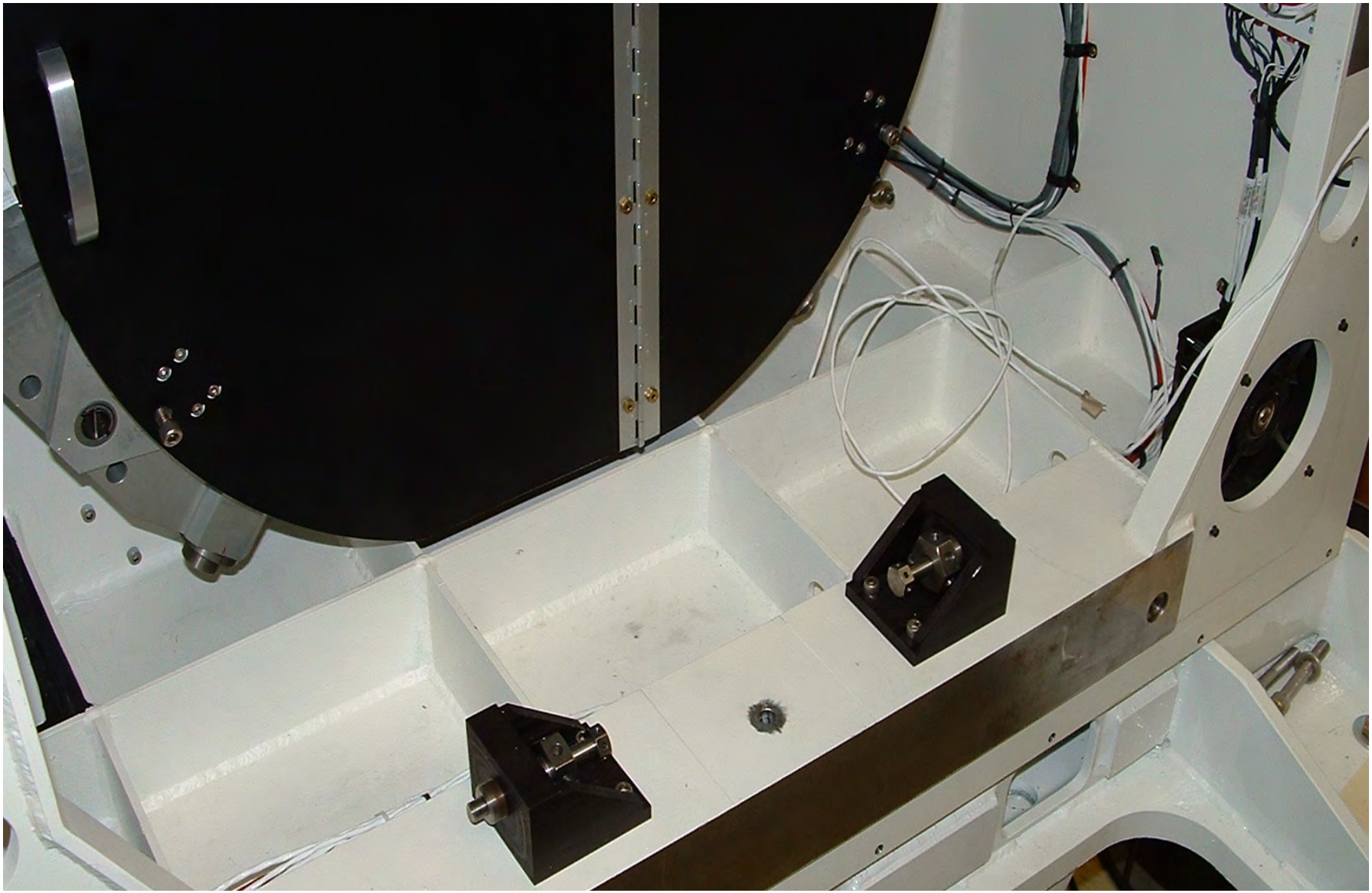
The telescope is a quasi RC system and has to work with the corrector. The above drawing show there is a non-spherical aberration position on the axis which can be used for the primary and secondary mirror combination testing.

Alignment

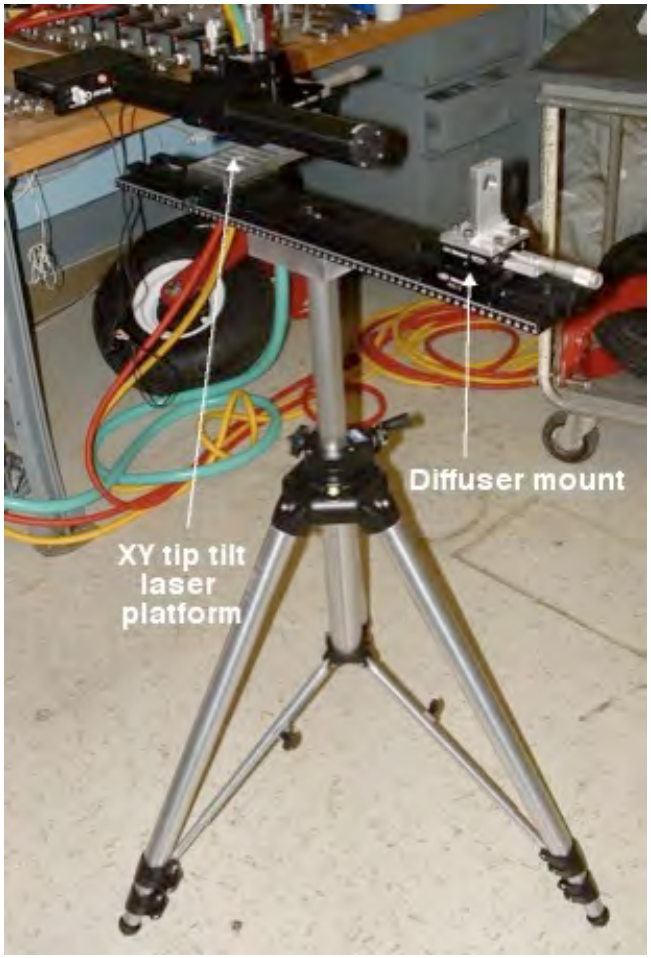
- Position optical elements in correct place
- Problem is to test whether element is correctly positioned and if not, in which direction it has to be moved
- Need a reference axis (at least two points)
- Mechanical reference (2 fiducial points)
- Optical reference (optical axis of element that is most difficult to move, e.g. M1)

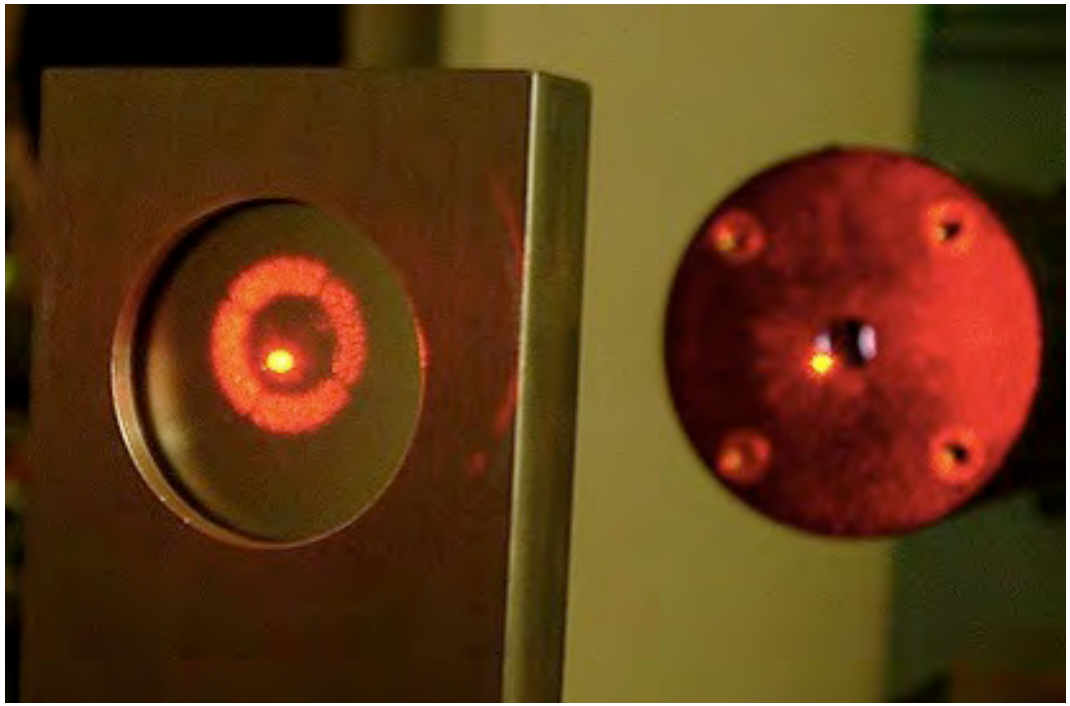
Alignment Plan

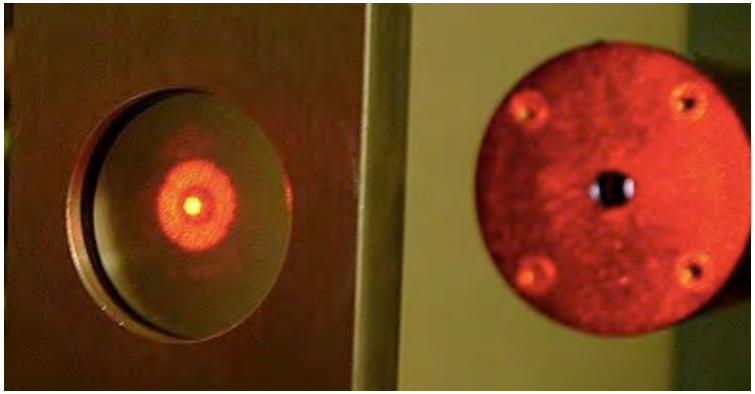
- Preparation, location
- Materials needed
- Software needed
- Precautions (covers for optical surfaces)
- Installation
- Initial alignment
- Subsequent alignment (during operations)

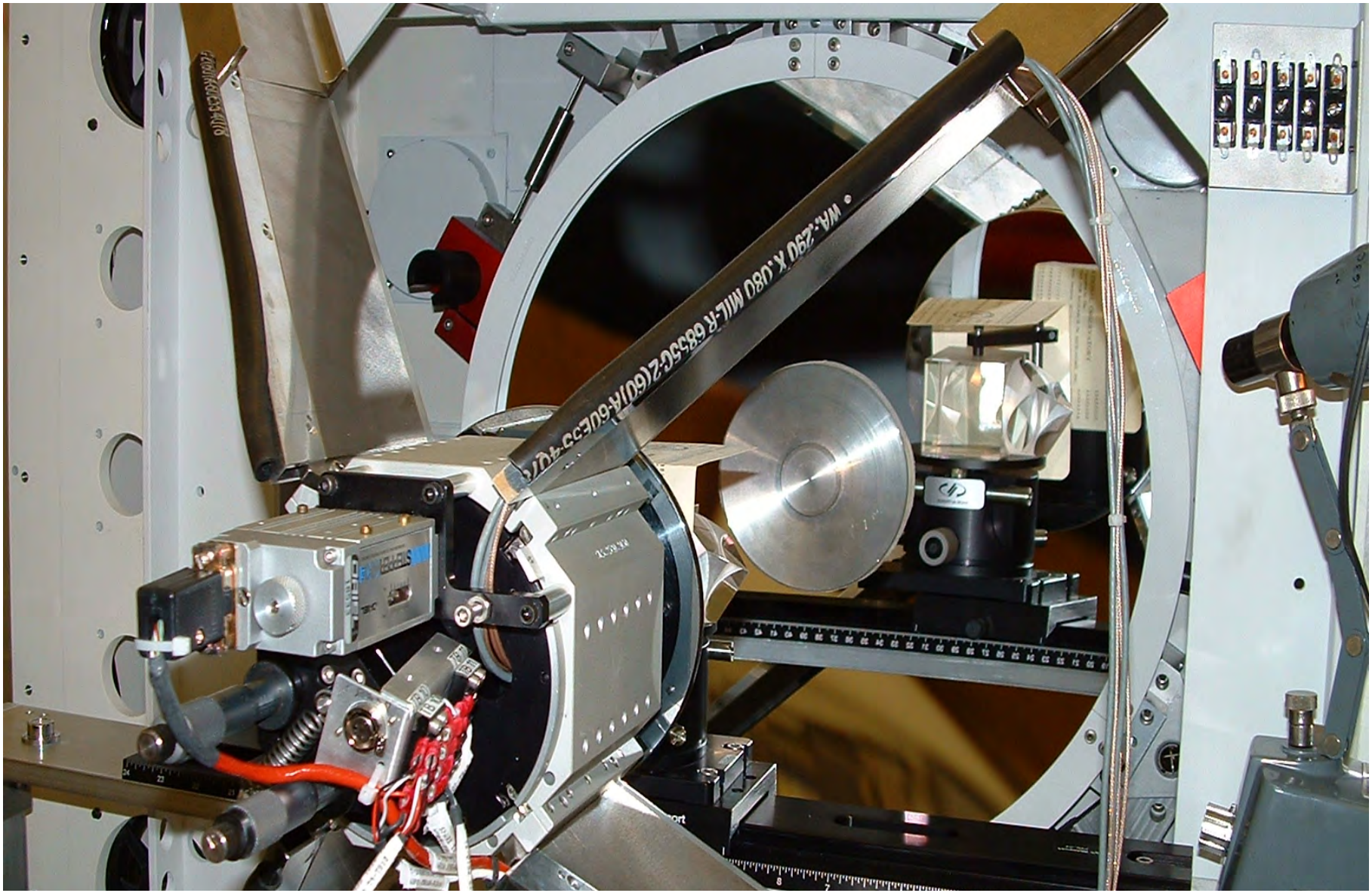


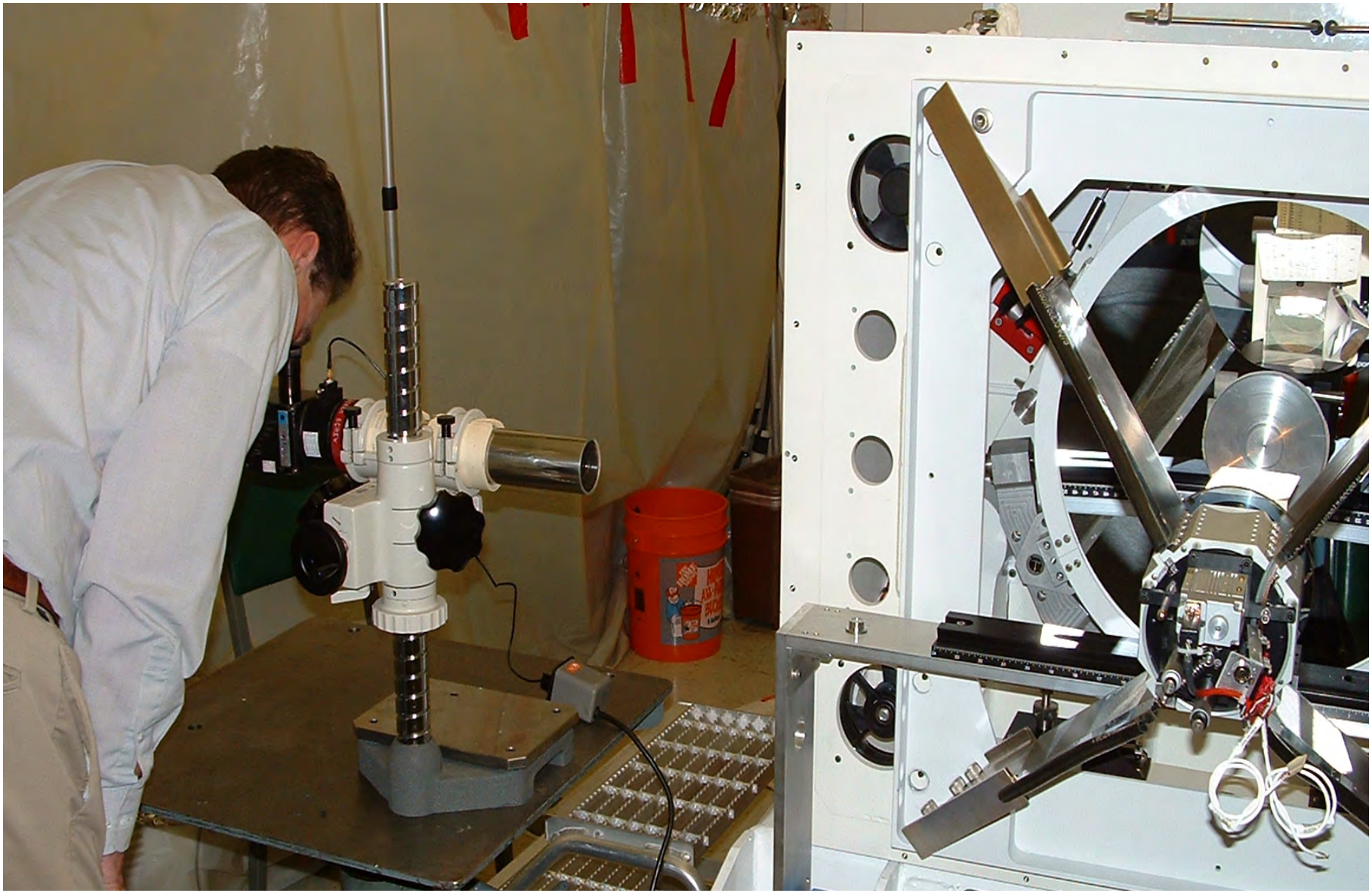
Optical Axis Determination

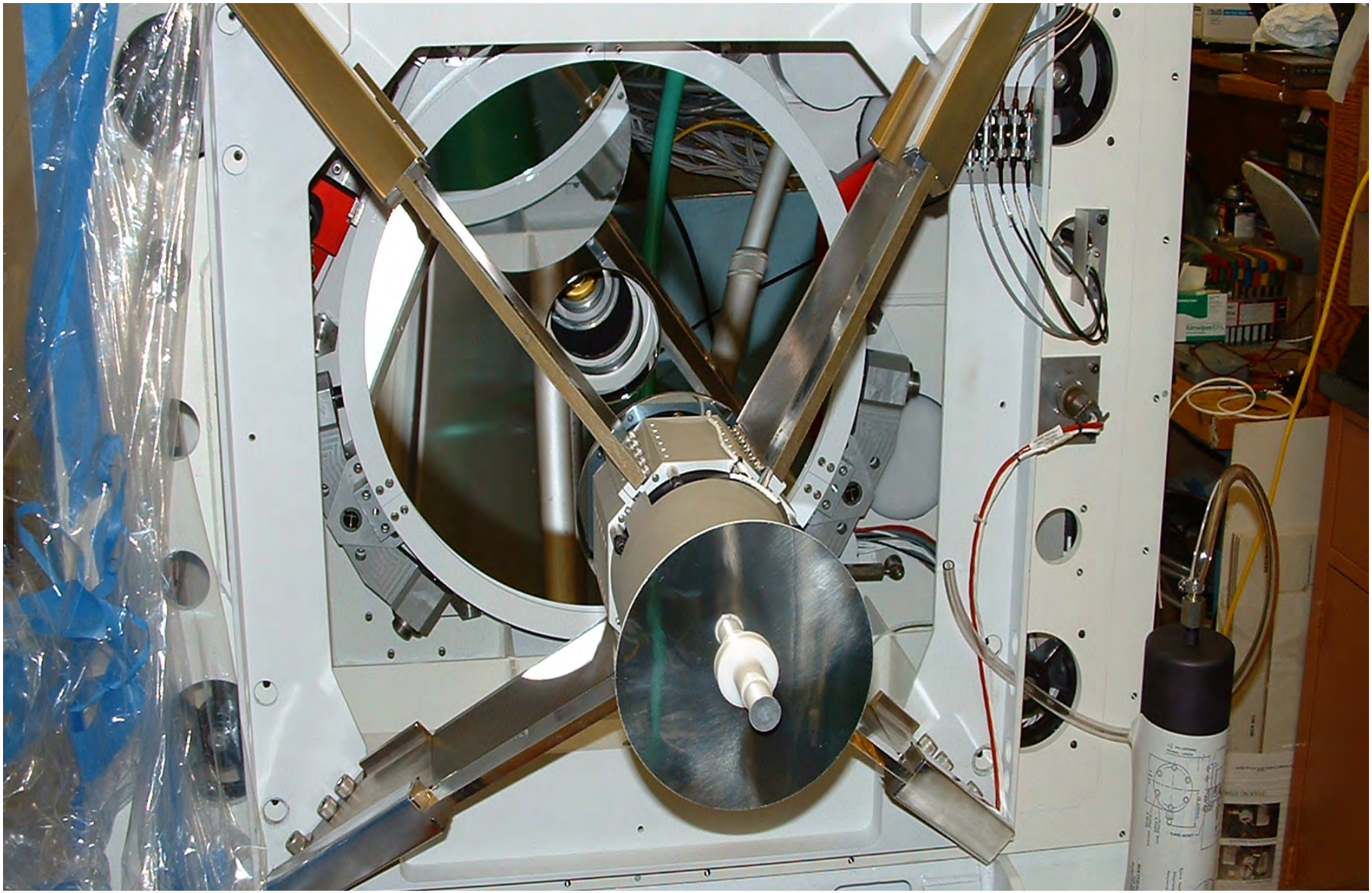






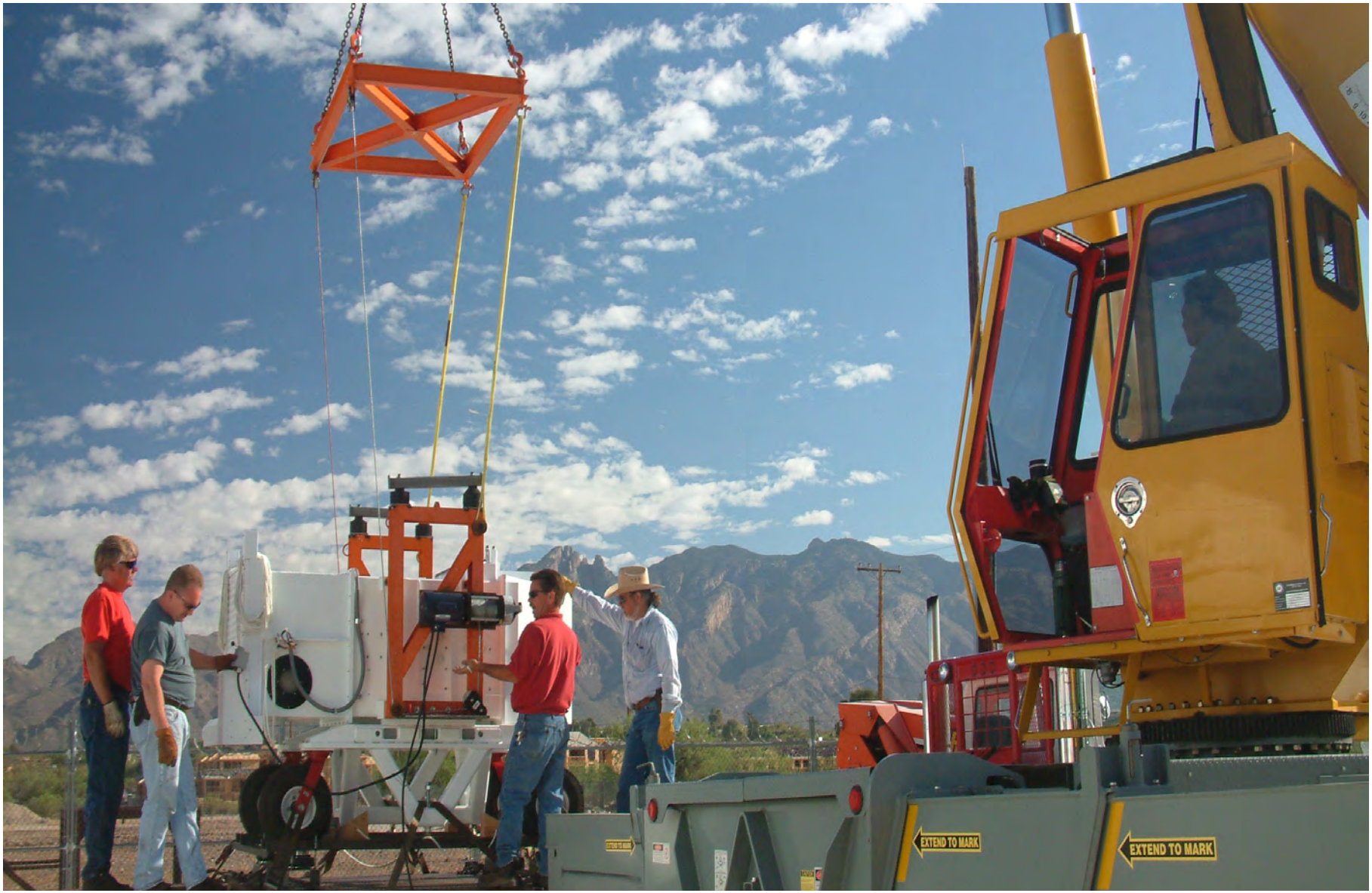







CAUTION
CAUTION
AA 1418


MACK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