# Transcription of interview by John Glaspey with Gary Poczulp, NOAO Optics Lab, Tucson, AZ, February 2020

recorded by John Glaspey
Feb. 28, 2020

Gary has put together a loose-leaf binder of a lot of photographs of projects he has been involved with – and he is often in these pictures – and there is a lot of history to understand there, and especially there is a lot of information and perhaps people wouldn't understand what is being done or the tools, and what's going on, so I thought I'd like to ask Gary to go over these and not just identify the people, which we definitely want, but also to say why this is particularly interesting, from the point of view of the development of the optics project.

First, Gary wanted to give the correct pronunciation of his last name, which is pronounced "pos-zulp", the c being silent.

## Change Record and Explanatory Notes

| | | |
|---|---|---|
| Glaspey, John | May 2023 | Changes/additions to the transcribed text and editorial notes made by John Glaspey are in curly brackets. Time stamps for interview are in bold. |
| Poczulp, Gary | June 2023 | Gary, in conversation with Sharon, briefly reviewed the text. Corrections (other than typos) and additions he made are added in square brackets with the text to be excised/replaced maintained but crossed out. |
| Hunt, Sharon | July 2023 | Proofed material and corrected errors in transcription (typos/names/commas/caption style). Formatted file, adding page breaks, footers with page numbers, and running heads with document title; italicizing image captions; and adding boldface to timestamps.<br>Created table of abbreviations used in transcription.<br>Posted digital copy to website. Maintained physical copy in NOIRLab Tucson Headquarters Library Archival Collection.<br>Corrections and additions by Gary to material that is in recording are in square brackets.<br>Editorial notes by John are in curly brackets.<br>Note that some of the captions need to have content added by John and/or Gary Polczulp (marked as "TBD"). |

*Caption: Larry Barr (left) and Gary Poczulp (right) examining the WIYN primary blank after it was delivered to the Optics Shop*

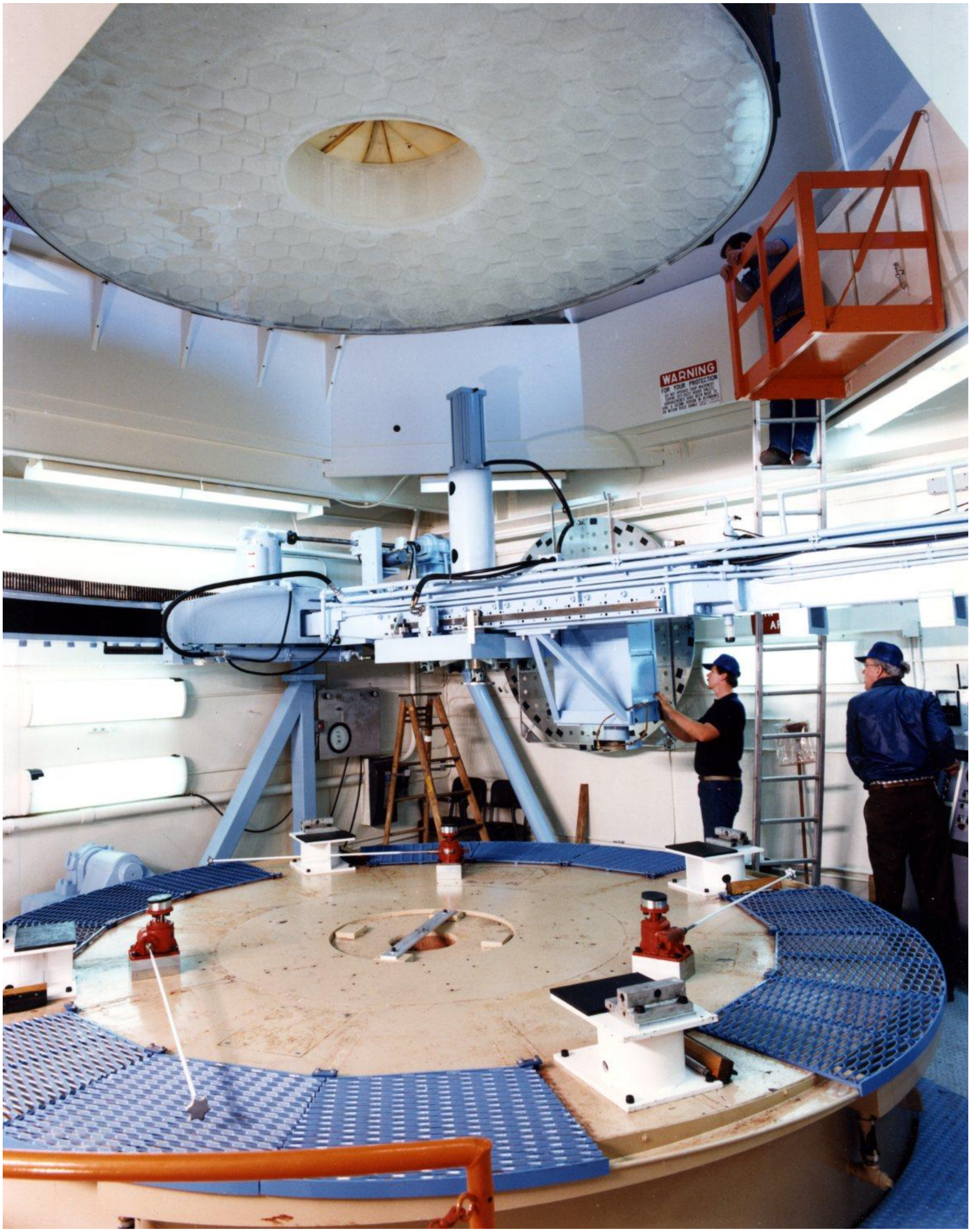
To start off looking at the first picture here in the picture book of the WIYN Telescope and the fabrication of the WIYN primary mirror. It's a picture taken at the UA Mirror Lab after the WIYN mirror was cast. There were three 3.5m mirrors that were cast: for WIYN, ARC, and the Air Force Phillips Lab. The Phillips Lab mirror, although it was cast last, it was finished first, because it was to go directly into a telescope; it was polished at the Mirror Lab. It was David Anderson and Dean Kettleson who worked on that one.

The ARC mirror for Apache Point was cast first but finished last. That was because the ARC mirror – there are some pictures later in the book – went out to Norm Cole's shop up on the north side of town, as a private contract to finish the mirror. Unfortunately, he was not able to finish it satisfactorily, and it came back to the Mirror Lab and was finished off there.

In the meantime, the WIYN mirror, the second one to be cast – in December of 1988 – and we received it here (there was a big party when the mirror came in) on March 17, St. Patrick’s Day, 1989. That’s when it rolled into the shop. This picture has Gary in the Hawaiian shirt and Larry Stepp looking at the back side of the mirror casting. Larry Stepp was the Project Manager for the WIYN primary polishing. At the Mirror Lab, after the glass was melted and the oven was rotating, and it was all up to temperature, they would do a quick cool-down by lifting the oven lid a few feet to dump some of the heat and set the glass. Then they would lower the lid back down and keep the oven rotating as it annealed for several months, meaning the temperature would slowly be brought down.

*Caption: Gary Poczulp (left) and Dan Watson (right) of the UA Mirror Lab*

The mirror is in an unfinished, rusty steel handling band as it is being taken out of the {editorial note: transport} box in the high-bay over at the NOAO Optics Shop. This handling band is still being used to this day, having been finished off and painted a bright yellow. Dan Watson of the Mirror Lab was integral in the casting operations. This picture was taken on March 17, 1989, St. Patrick’s Day.



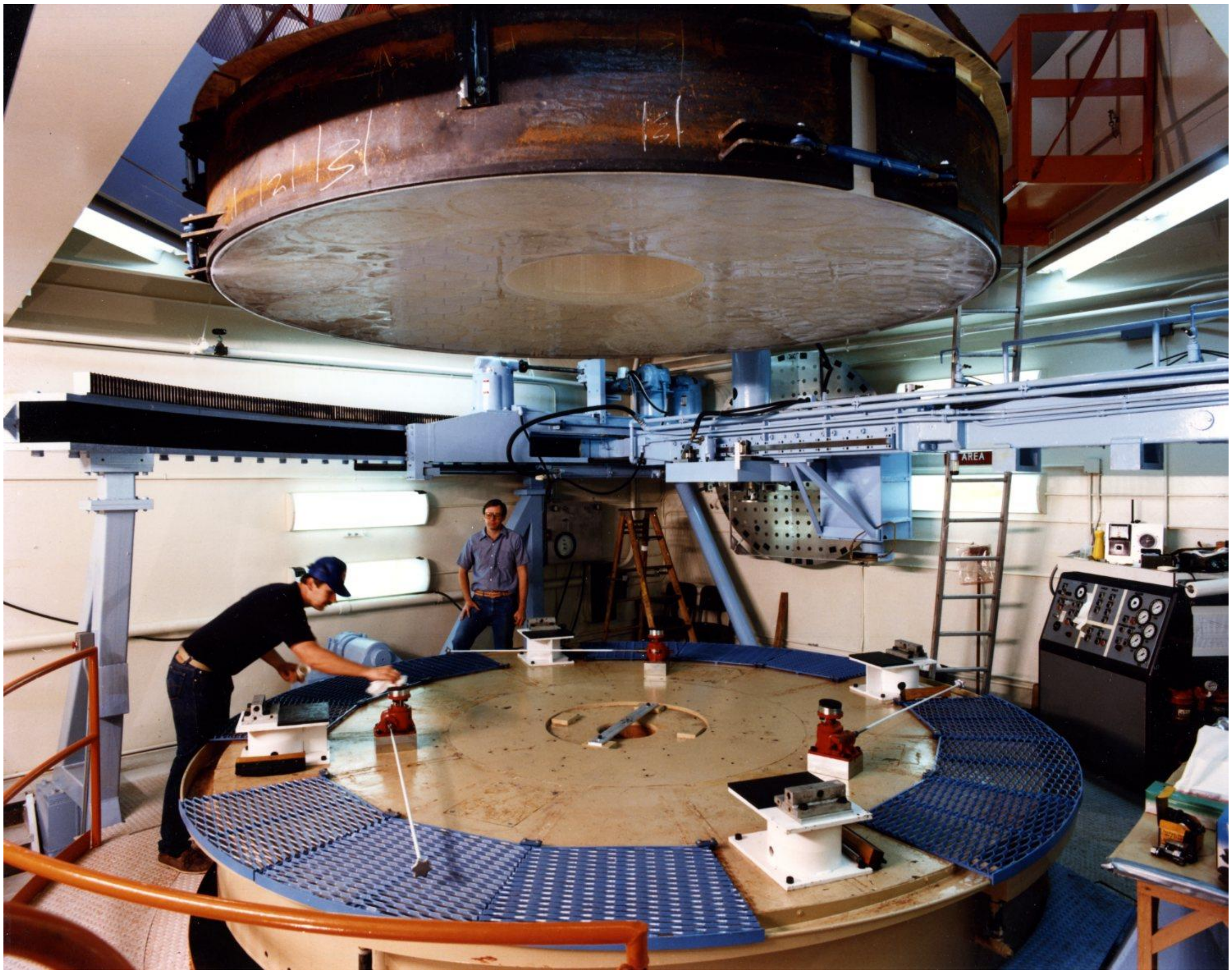
*Caption: Gary Poczulp next to a ladder and John Richardson at the controls of the polishing machine*

This shows the polishing table with the mirror overhead suspended from the crane. There are three prominent red pneumatic jacks that are meant to support the mirror with what will be the optical surface face down. It will be supported on three points while work is done on the back side, leaving the final polishing on the front surface for last.

This is the 4m machine, with the blue structure overhead is the Pitman arm which will take and position our tooling over the mirror. The brown/tan table with the blue floor grates on it will rotate. One of the interesting features of this machine is that it is all hydraulically driven. This machine was used to make the two 4m mirrors for KPNO and CTIO, the Mayall primary and the Blanco primary. It was also used for making the NASA IRTF mirror in the late 70s.

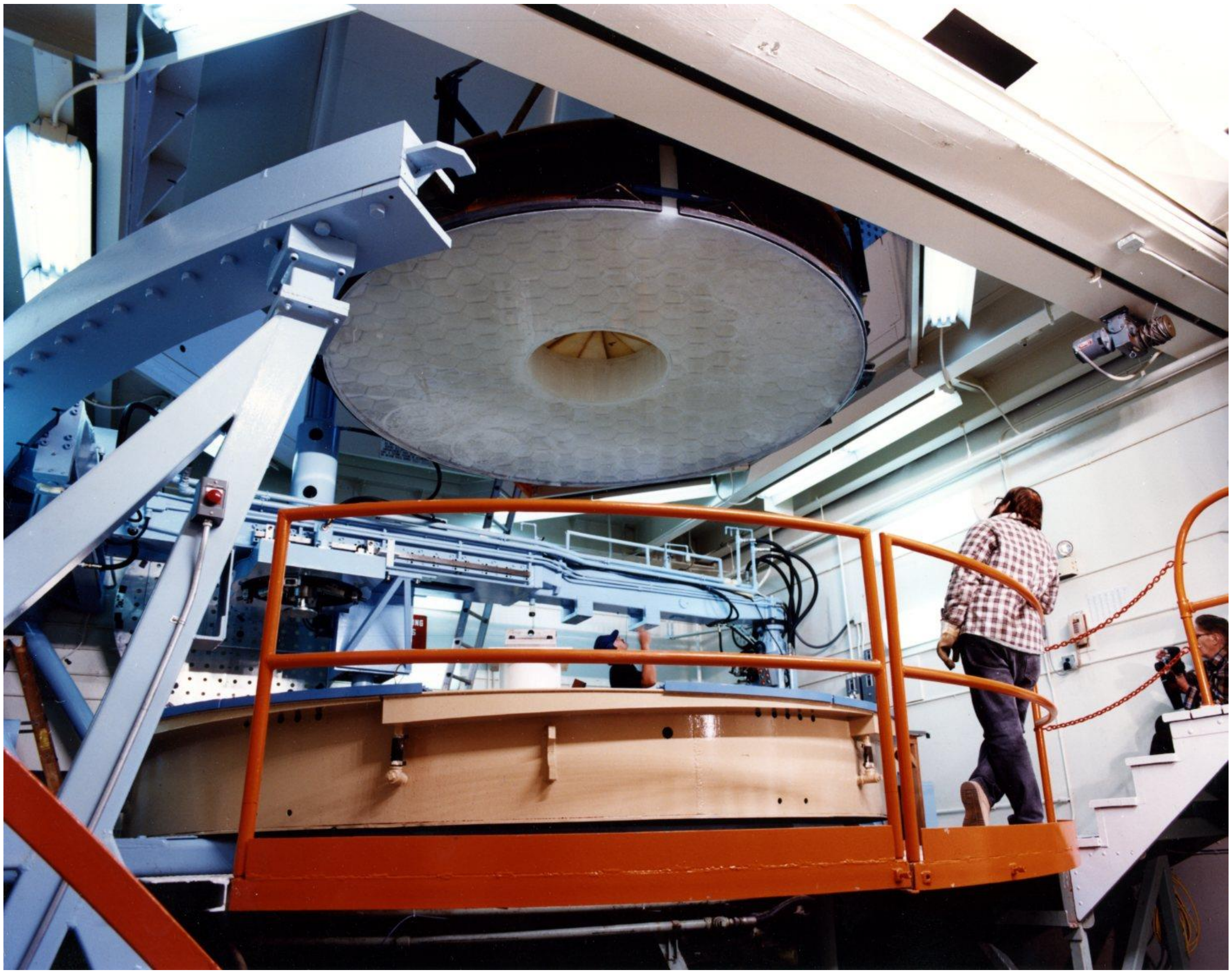
Gary had been at the Optics Shop for 8 years, having started in 1981. His main function was testing the optical surface. Although they knew that this mirror would eventually end up in a telescope, its main purpose was the technology development program. They needed to learn how these spun-cast borosilicate mirrors should be supported and how to maintain their thermal stability by blowing temperature-controlled air up into the 296 cavities. At the time nobody was exactly sure how to do that nor what sorts of measures they would go through to achieve satisfactory control of the mirror surface. So, one of the reasons it took so long to finish the mirror was that it was a technology demonstration to show how you could polish these mirrors to make them work in a telescope. As a result they did a lot of testing that would not normally be done if you were going straight to making a mirror that would go in a telescope.

There was also a 72 inch (1.8m) mirror from the previous generation of castings from the Mirror Lab. One of the last castings they did of that size was the 1.8m f/1.0 mirror for the Vatican Observatory, a very “fast” mirror. They did several 1.8m castings that were meant to mimic the MMT mirrors, being f/2.7. NOAO had one of those mirrors for a while that they did some testing on polishing work and some thermal tests. They installed several resistors to heat up one core, then tested it optically to study the effects. This was done for a few years before receiving the WIYN 3.5m mirror.



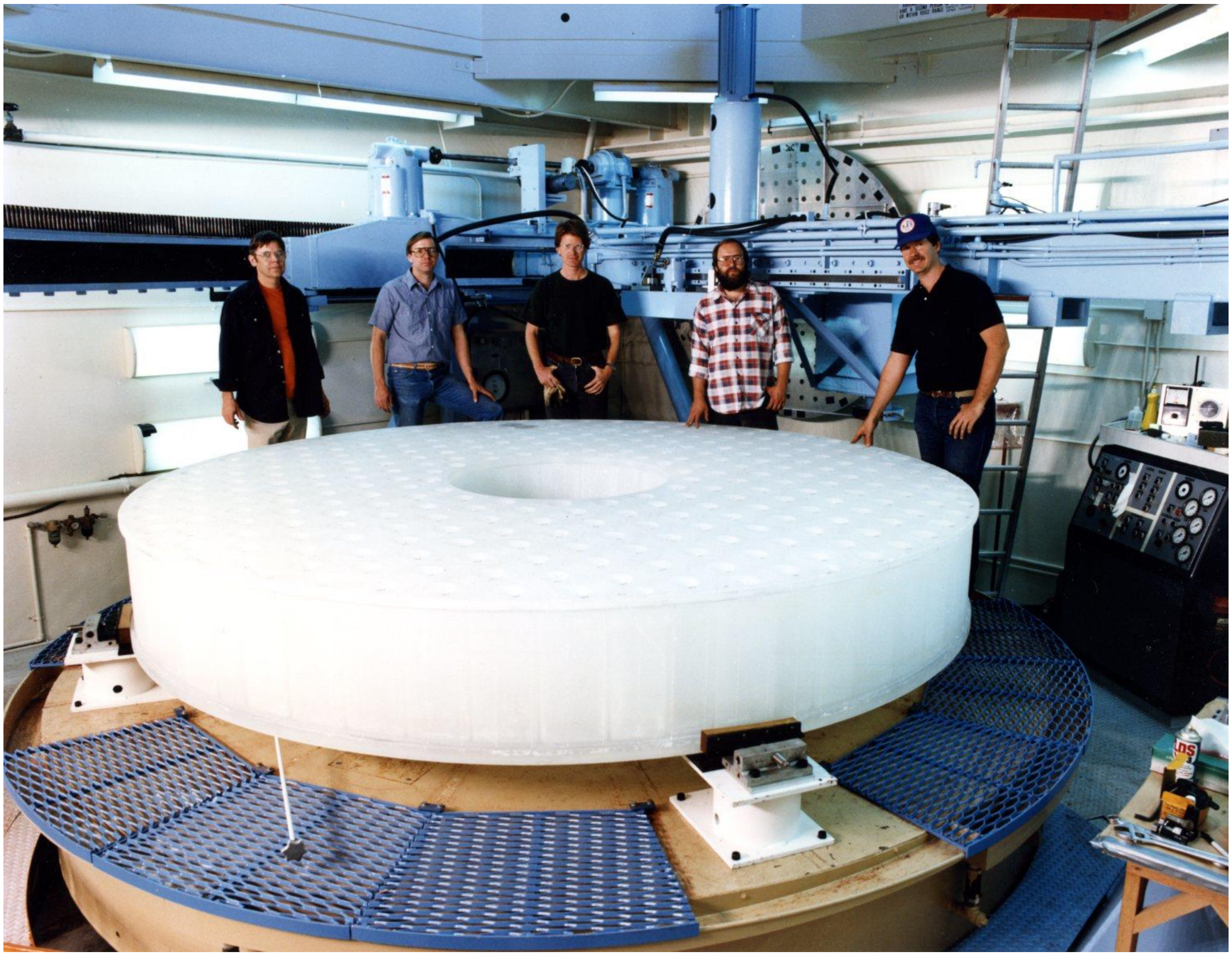
*Caption: Gary Poczulp (left) and Larry Stepp (right)*

This next photo shows the mirror a little lower down. Gary was putting a light layer of grease on the top of one of the pneumatic jacks. Which were controlled using the white rods on each. With this fairly crude support setup, they would only be working on the back side and on the edge.



*Caption: Dan Watson leaning against the railing; Frank Vaughn, who worked In the small shop, was taking some pictures as a record; and Gary Poczulp in the background*

This is the same setup, viewed from the basement level looking up past the orange guard-railing of the bridge that goes around the table for the 4m machine.



*Caption: Left to right: Ed Mannery of the University of Washington, Larry Stepp, Robert Ford of SOML, Dan Watson of SOML, and Gary Poczulp*

This is a group shot once the mirror was out of the handling band and sitting on its supports. The edge “arcs” are in place to keep it centered and from sliding off the table. The controls for the machine are in the background, as is the escape ladder to get out of the grinding room.

*Caption: John Richardson*

The mirror is on the polishing table as they do a fixed abrasive grinding via a bronze diamond-impregnated wheel being used to take a skim-cut off of the back. This provides a ground surface on the back. John Richardson is using a squeegee to clean off the ground-up glass and the coolant by pushing them off the edge, where the plastic skirt directs it into a drain pan so that the coolant can be recycled. The diamond wheel is spinning at a fairly high rpm and the mirror is rotating slowly underneath the tool, which moves gradually from the edge of the center hole outwards to the outer edge over a period several hours. The small white circles are rubber pads that had been installed inside each of the 296 holes for the mirror temperature control air that would be blown into the holes during observing. These pads, which were below the back surface so that the grinding wheel would not touch them, prevented the cavities from filling up with coolant during this grinding process. The idea here is to get a smooth, ground generated, flat surface that relied on the geometry of the machine to go straight across once the mirror had been leveled in preparation for this step. This is the rough work that takes place before any loose abrasive grinding.

*Caption: Left to right: Gary Poczulp, John Richardson, and summer student Mike Roman*

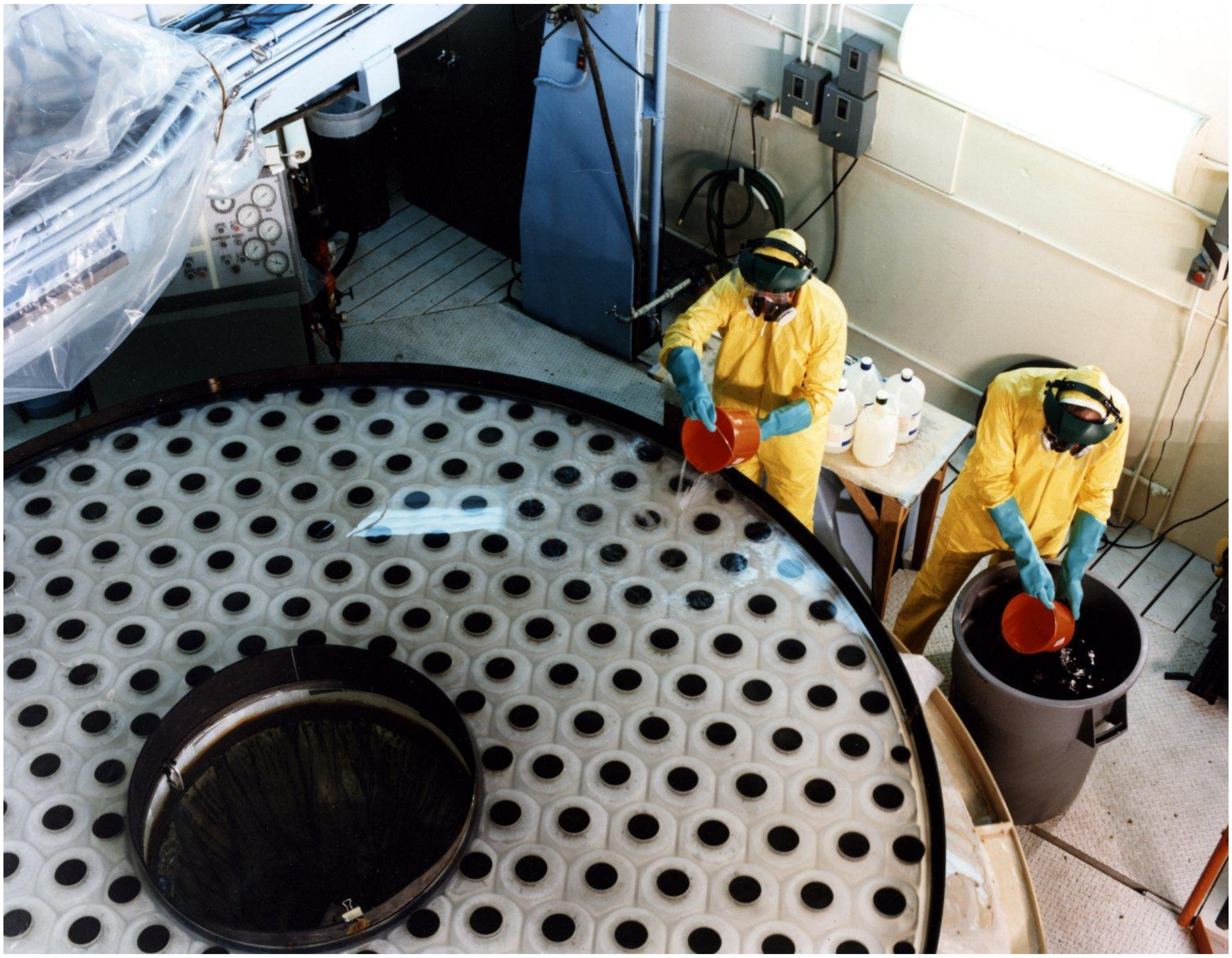
Gary is putting grit on the sidewall of the mirror while at the same time there is a tool doing loose abrasive grinding on the back surface of the mirror using a carborundum grit, probably either 80 grit or 220 grit. For the edge, they had a steel mesh band that was tied off at two places and was rubbing the grit against the sidewall of the mirror. At this point the rubber plugs are still in the 296 holes. This is one of the messier operations.

The nest of hoses over Gary's head are for the hydraulic motors that drive the motions of the table and the Pitman arm. The mechanism above the tan tool is for providing more or less grinding pressure of the tool on the mirror. The hydraulic system allow the pumps for the hydraulic motors to be in an adjacent room, isolating the heat they generate outside the grinding room where they have to do optical testing. The heat from large electrical motors would interfere with the optical testing especially during polishing and figuring stages.

*Caption: Gary Poczulp*

{editorial note: per Gary, he will rewrite this paragraph – the pneumatic router was done with plugs in place – not flooded with water. Plugs removed after router work and before hand lapping with hemispherical tool.}

Gary carrying out the probably unenviable task of finishing off the bevels on all of the 296 holes in the mirror for which the rubber plugs have been removed. The core material from the casting left a very rough edge on the holes on the back side. The first step after the plugs were removed involved pneumatically driven air motor that was on a plexiglass frame that basically looked like a router. It had a fixed diamond abrasive wheel that would spin at a high RPM. After flooding the hole with water, he would bring this against the edge of the hole. Cam-followers would make it go around and make a rough bevel. In the photo Gary has a 5- to 6-inch diameter smooth, hemispherical grinding tool with which he is lapping the edge of all of the bevels by using a carborundum grit, probably 220 grit. The tool is pretty heavy. {editorial note: per Gary, he can get a better weight}, perhaps weighing 10 pounds or so, but he would have to spend about 5 minutes on each of the 296 holes. Note that the tool has a nice handle to minimize the risk of dropping it on the glass surface.

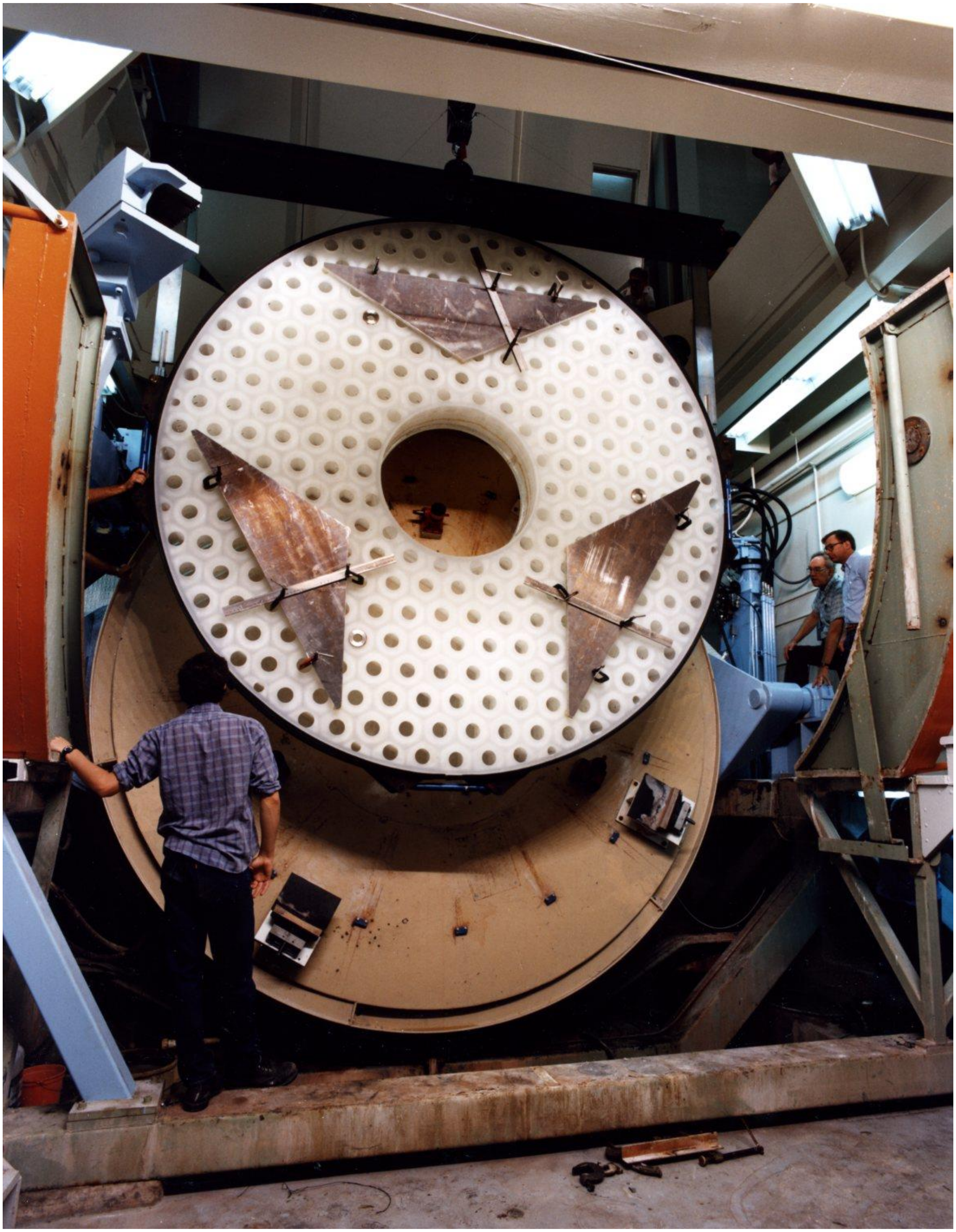


*Caption: TBD*

The mirror is in the main part of the picture with the rubber plugs put back in, and there is liquid covering it. The two people are in hazmat chemical suits with green gloves and orange buckets. This is from the wet run when they were acid etching the back surface of the mirror. Acid etching of the glass is accomplished with hydrofluoric acid – very nasty stuff to work with. It etches glass so they are using plastic bucket and a plastic trash can. They are actually using water in the picture, although in the background you can see the plastic bottles of the acid. There are dams installed around the inside edge and the outside edge of the mirror to contain the liquids. The water is being used to test for leaks before they use the acid. They had the company safety officer – probably Mack Rhodes – upstairs near the large exhaust fan to draw air out of the grinding room. He had attached a large flexible hose to direct the air out of the high-bay doors to vent the vapors outdoors. (He doesn't know if anybody's windows got etched that day.) The purpose of the etching was to remove the microscopic fractures/cracks at the bottom of the pits created by the grinding grit. The acid blunts the propagation tip of these fractures, thus making the glass stronger.

You can achieve the same results, effectively by polishing with finer and finer grits, then polishing the surface to remove the subsurface damage, i.e., by mechanically removing it. Etching is a more expedient way of doing this, albeit a little bit riskier. They were double gloved and double suited since they were working with large amounts of hydrofluoric acid. For all of the 8m mirrors they have been doing, the Steward Observatory Mirror Lab, by contrast, polish the back surfaces, although not to the precision desired for the reflecting surface. The back surfaces of these mirrors will have a large number of supports attached, which will be active supports, so you will be constantly pushing and pulling on the surface, so you want a strong surface to work with.

Gary explained that for this particular operation there was no need to filter the air coming into the area, since they had left the hatch open. The building air handling system is designed so that when the hatch is closed this area is positively pressurized, so the air inside is always trying to escape from the area. During normal operations they only needed air that uses the standard building filters for the air pumped in.

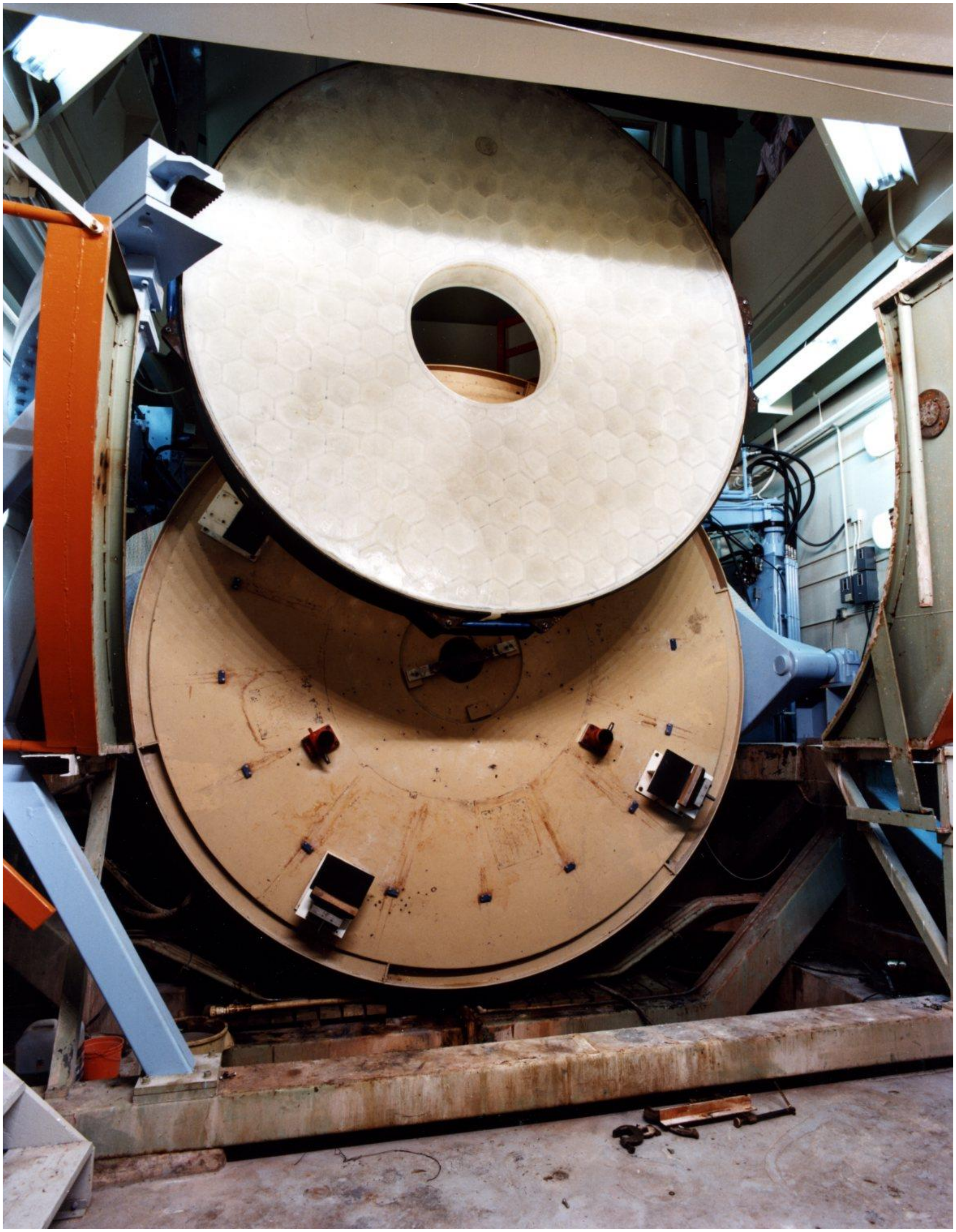


*Caption: Left to right: Mike Roman, John Richardson, and Larry Stepp. (Gary is at the top handling the crane controls.)*

The mirror is shown being tipped on its edge. Three triangular steel plates have been attached to the back surface using C-clamps that go into some of the holes. The plates are held in place while the mirror is being flipped over. Since they will be working on the front surface, they have gone from the 3-point support used to work on the back to a 9-point support, which is adequate for the rough shape they start with on the front.

This process involved lifting the mirror with the table horizon-pointing and moving the crane to separate the mirror from the table in a gentle way.

Gary wanted to credit Larry Stepp, who arranged for someone from the Photo Lab, either Mark Hanna or Glen Pickens, to come down whenever any important move or process was happening.



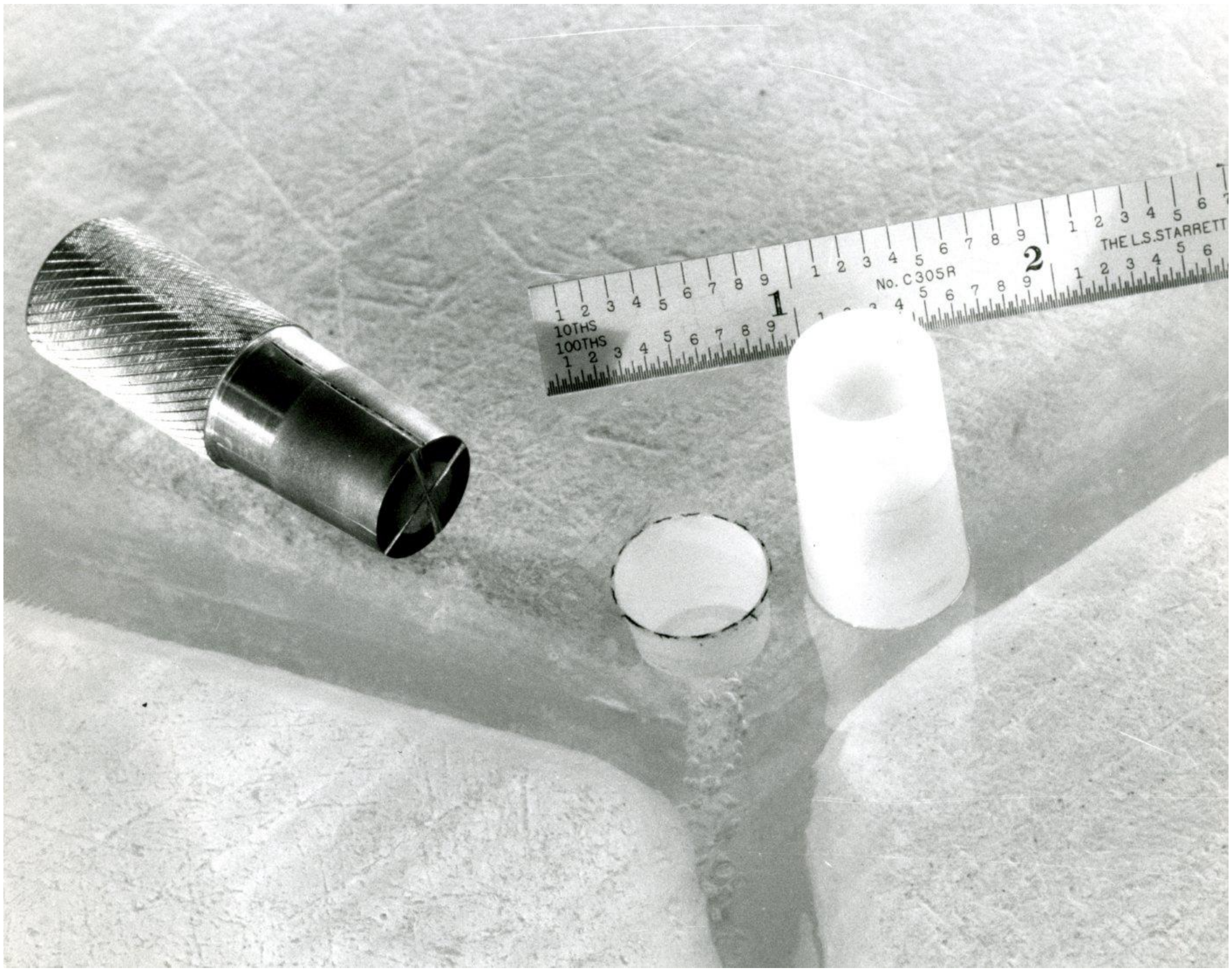
*Caption: TBD*

The mirror is horizon pointing suspended above the horizon pointing table. This was one of the advantages of this table that it allows us to, when the mirror is attached – or in this case when it is not – bring the mirror up, rotate it, the bring it back down so that the metal plates which had been temporarily attached to the back side would then interface with the three jack stands, as well on the outside edge, against the four edge arcs that held everything in place.

*Caption: Gary Poczulp at the grinding table controls*

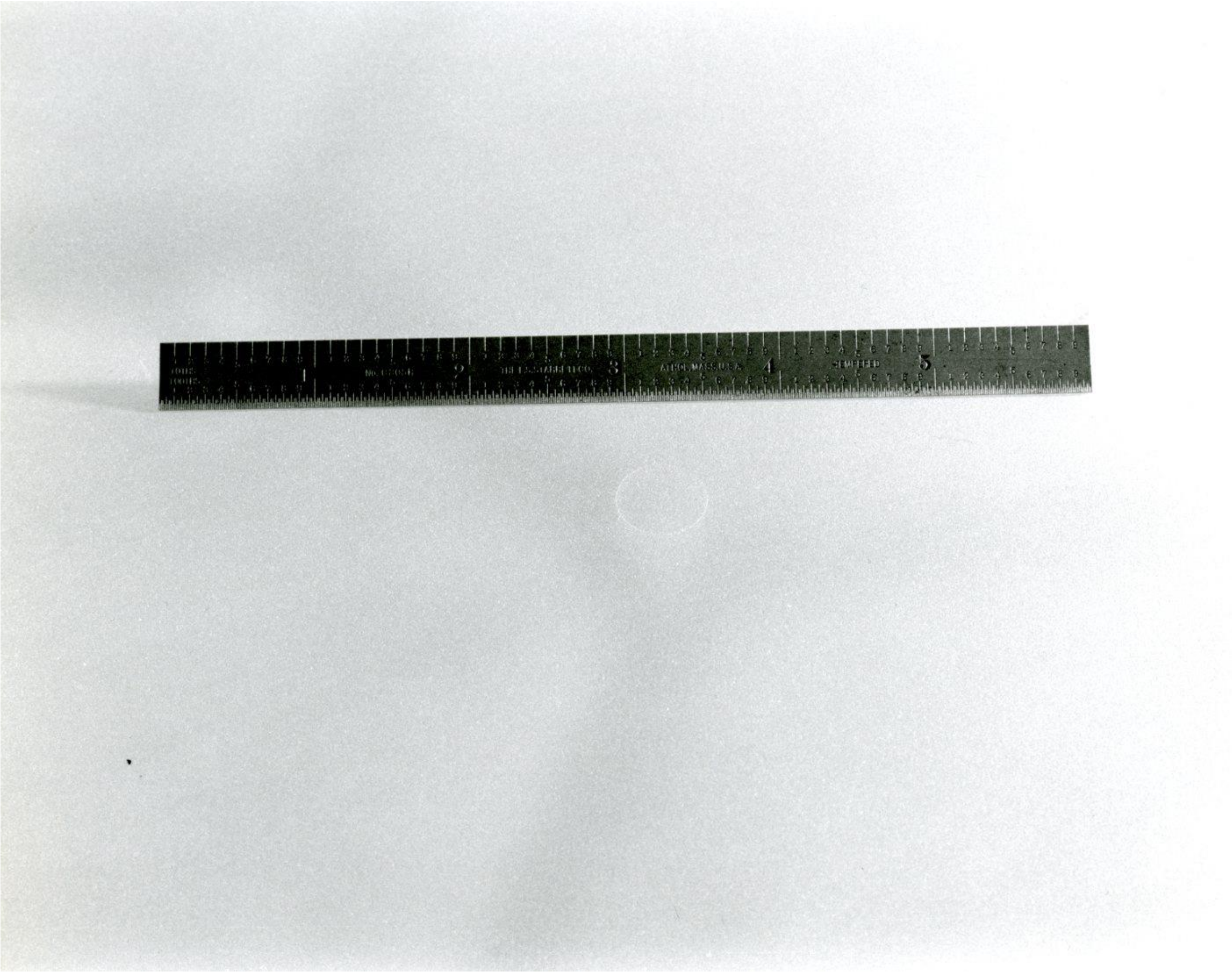
**(00:34:15)**
This shows the use of a diamond wheel for abrasive grinding of the front curved surface of the mirror, where Gary is acting as a protein (human) servo while he was watching the display on a VT100 that showed the surface height should be as a function of radial position, and he made sure the grinding tool was at the correct height. Since it took several hours to make each radial pass the height would have to be jogged upwards a few thousandths [of an inch] every now and then. The blank comes out of the oven with a curvature on it already created by the 6–7 rpm spinning of the oven, but is initially 35–40 mm thick, whereas they were aiming for a final front thickness of approximately 30 mm. These skim cuts also remove the cruddy surface caused by stuff falling from the oven lid, but when these top few millimeters layer are removed they get down to the cleaner glass that will be polished.

In older mirrors like the 4m (Mayall telescope), most of the mirror was made from over 16 tons of pyrex boules that were melted to provide the mirror mechanical support. A layer of higher optical purity was added to this, then polished to provide the reflecting surface. For this mirror at the Mirror Lab, they went through a careful selection process of picking uniform quality pieces for the jagged chunks of glass to put in the mold, so they did not need an additional layer on the top for polishing.



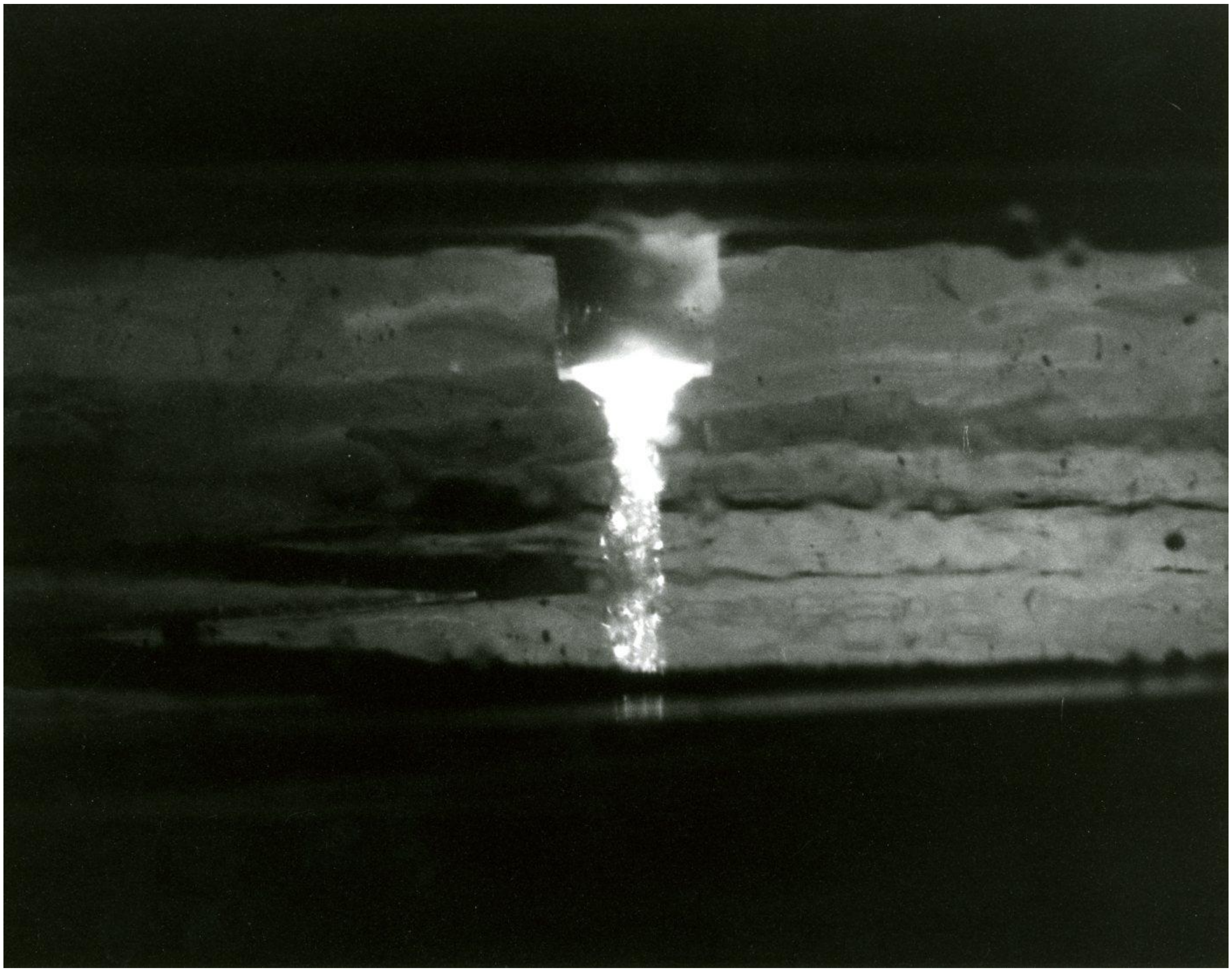
*Caption: With a steel ruler showing the scale, this shows a tapered tool made from brass, a glass plug, and a hole cut in the front surface of the mirror.*

**(00:39:05)**
The hole, just above a stream of bubbles that rose towards the as caste surface, was made where one big bubble made it up to the surface at the prescribed thickness of the mirror.



*Caption: The 6-inch steel rule is just above a faint circle, which is where the plug was inserted and the surface was ground.*

After the plug was inserted in the hole shown in the previous photo, the diamond wheel abrasive grating created a uniform surface of blank plus plug shown here. This photo was taken well after the previous, so the surface shown here had already been lapped with a loose abrasive.

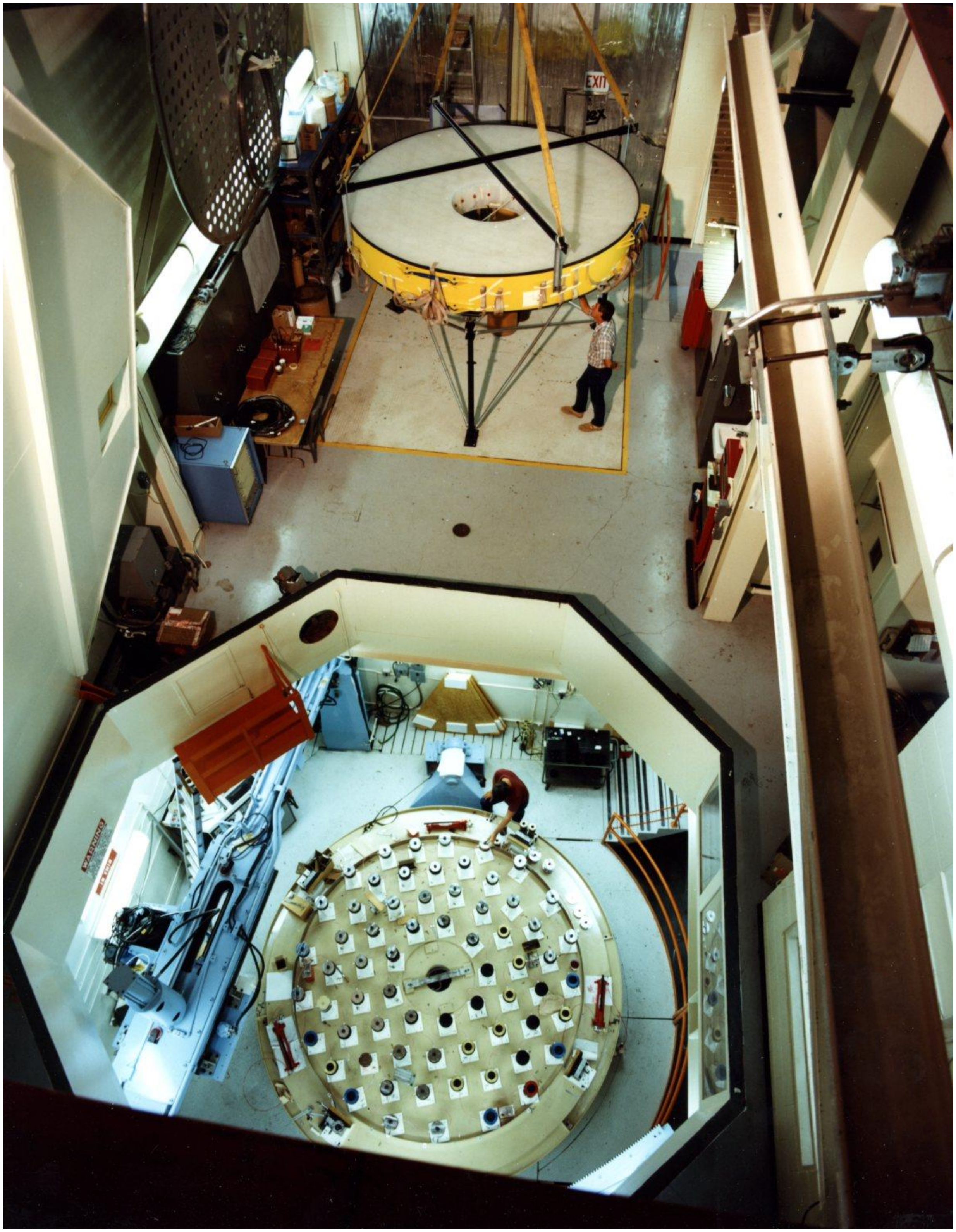


*Caption: View looking through roughly 8 inches of glass, illuminated to show the stream of bubbles*

**(00:41:00)**
A side view showing the tapered plug from the previous two photos in place.

*Caption: The underside of the mirror, supported by the now finished handling band, painted yellow*

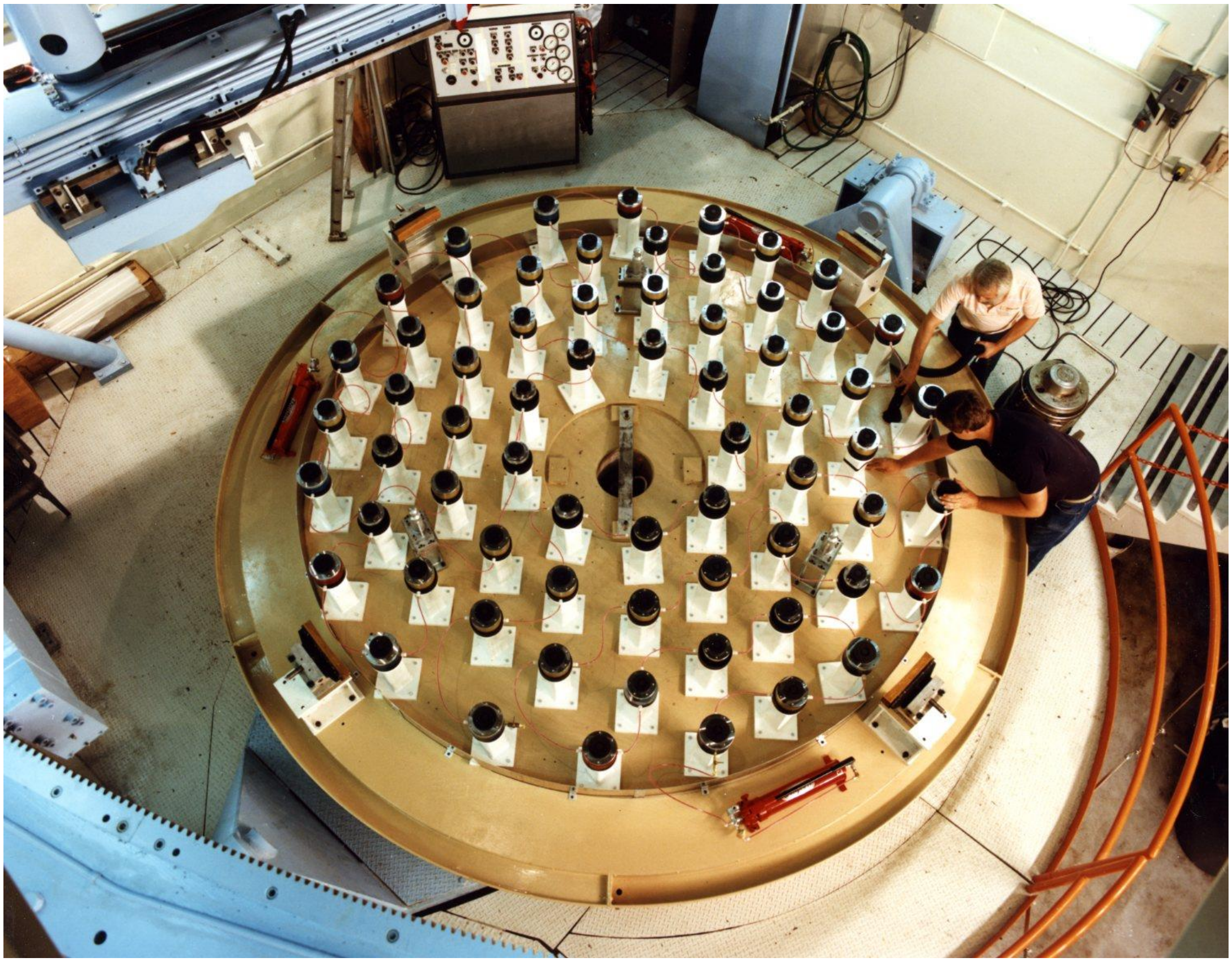
**(00:42:00)**
The view of the underside, showing the 296 holes, the orange safety railing, and the edge of the machine. Gary is probably at the top right controlling the crane. There are three stainless steel supports put into three of the holes for supporting the mirror during the rough grinding process. Here they were probably getting ready to install the polishing supports.



*Caption: Overall view of the shop taking from the stairs that lead to the top of the test tower.*

**(00:43:42)**
This view shows at the bottom the 66 axial supports on the polishing machine. The hydraulically operated supports were separate into three zones, so they could tip and tilt the mirror as well as raise and lower it. Gary is down on the table looking at one of the edge polishing supports. Upstairs, in the high-bay area where the removable floor is, Dave Dryden is seen looking at the underside of the mirror. At this point the mirror has been instrumented with 1024 thermal sensors that Dave put into place. The mirror is suspended from the crane but has a safety support underneath it in case the crane were to fail in some way. They were getting ready to mate the mirror with the polishing support. The 66 supports are at the same location as will be the active supports once the finished mirror is put into its cell, so that as you are polishing the mirror it is supported in the same way as it will be in the telescope.

This photo is out of order relative to some of the next few photos.



*Caption: Left to right: Larry Junco and Gary Poczulp*

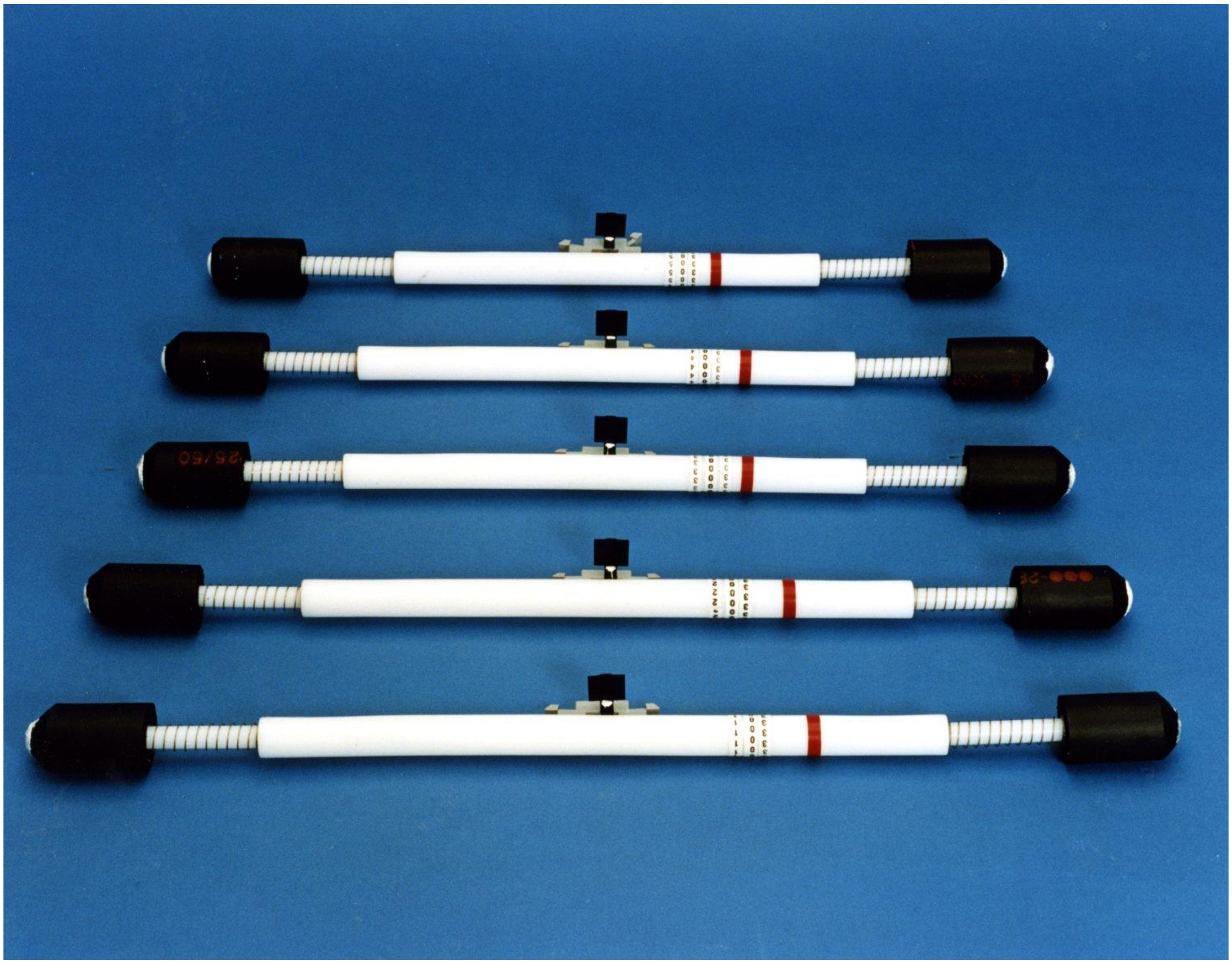
**(00:45:30)**
Larry Junco and Gary Poczulp at the edge of the table using a vacuum cleaner to remove debris from the machining process when they located the 66 axial polishing supports. Holes has to be drilled into the table to secure the supports. The three hydraulic jacks that control the three zones are seen around the edge of the table. The four edge arcs have wood plates at the inside of threaded screws that center the mirror on the table's rotation axis and constrain the edge of the mirror.

*Caption: Dave Dryden with one of the thermal probes*

**(00:47:04)**
Dave Dryden with one the 296 thermal probes. The cabling is dangling down from the edge of the mirror handling band. There are covers over the mirror surface, which would have been either a ground surface or even a generated surface. They had made a temperature calibration box into which all of the thermal probes would be placed and would be at the same temperature. Dave could read their values and get the individual corrections to have accurate temperatures.

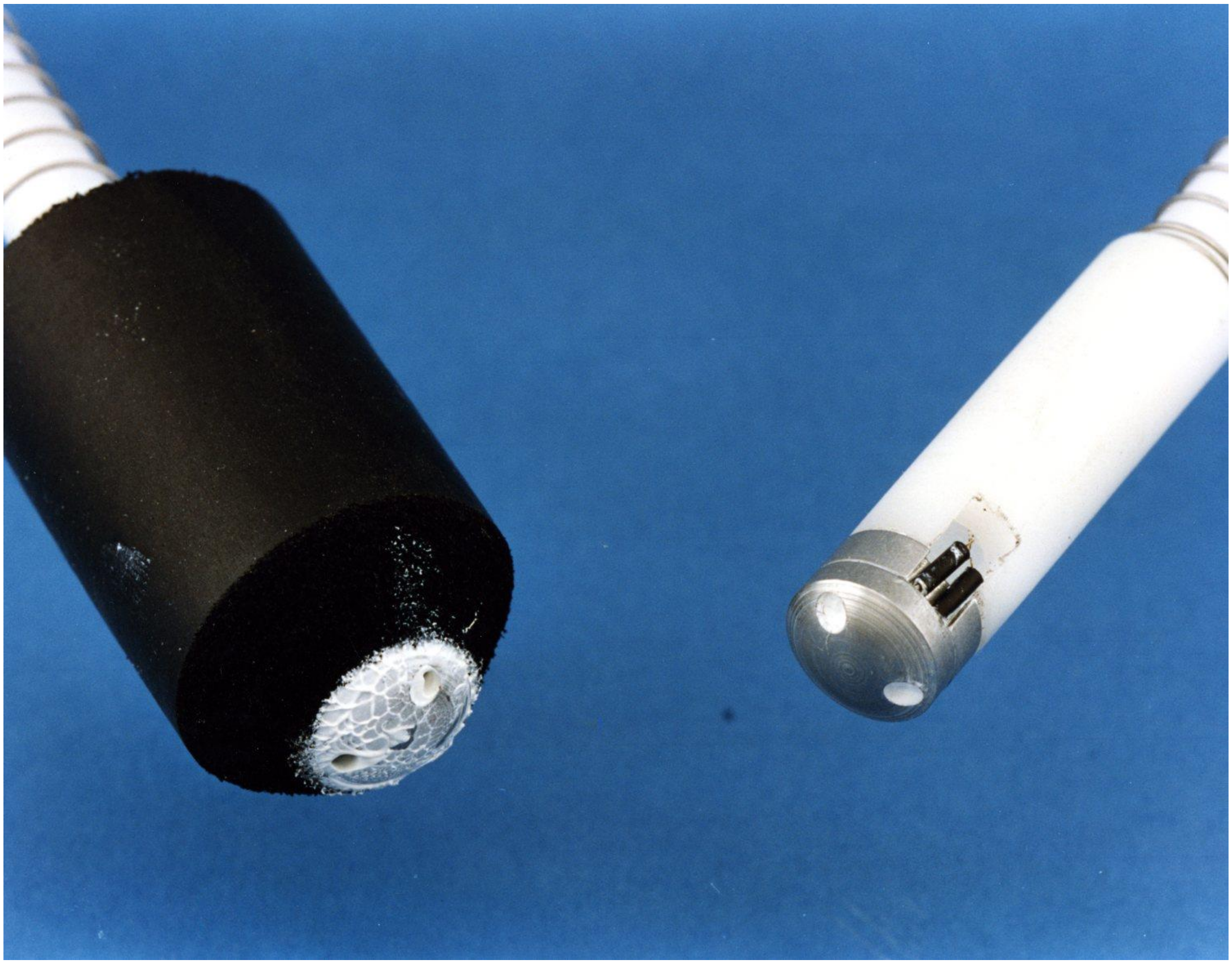
*Caption: Summer student Mike Roman*

**(00:48:04)**
Mike Roman installing one of the thermal probes into one of the 296 cores. Having to do this almost 300 times meant it was not a trivial task. Each probe had to be identified to know where they were for understanding the readouts. Since the core heights were different depending on how far from the center they were, the probe lengths had to be different as well. Near the center they were shorter, and farther out they were longer.



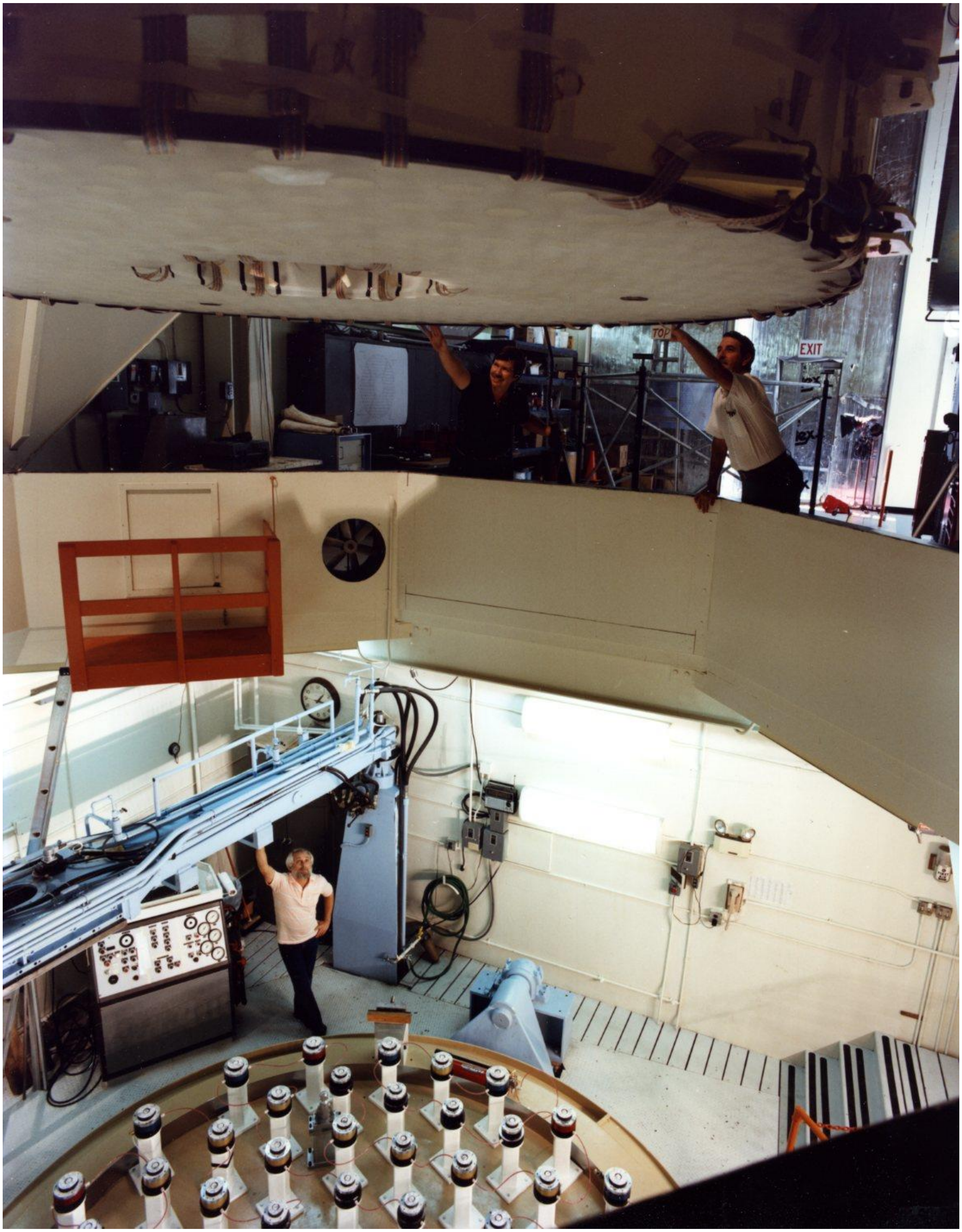
*Caption: Demonstrating the 5 different length thermal probes needed*

**(00:48:48)**
Five different-length temperature probes were needed. These were plastic with light springs on either end such that the tips with black insulating material around them that were tapered to fit into the fillet at the top edge of the core and insure that the tips were in good contact with the glass. They also have identifiers to indicate where they go and which is the top and which was the bottom via the red strips.



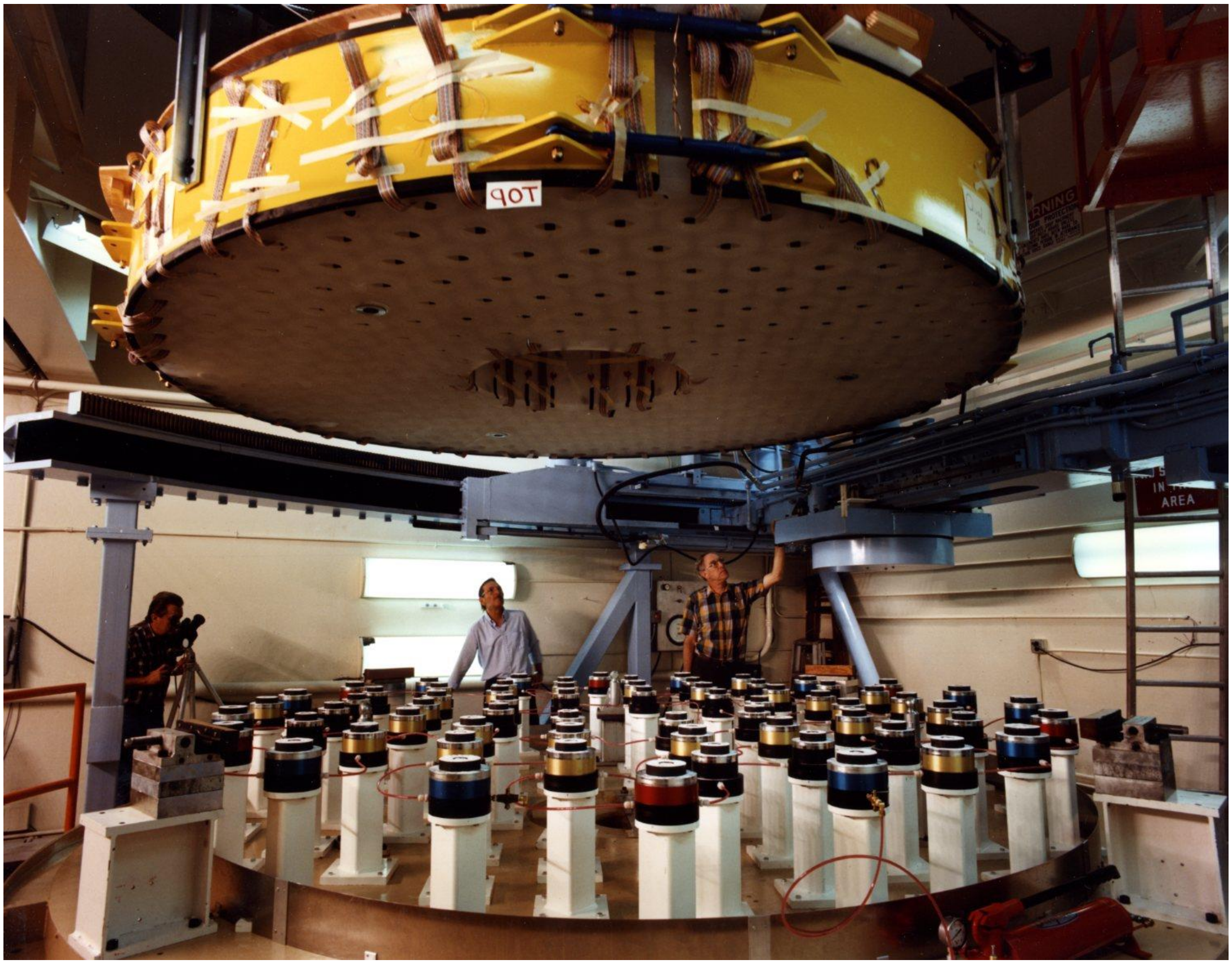
*Caption: TBD*

**(0:50:09)**
This is a close-up of a thermal probe tip. They were measuring the top of the mirror bottom plate, the bottom the top plate, and the air temperature at each of the 296 cores, and they epoxied sensors on to the inside and outside diameters. These were all multiplexed into the readout system. It took about 20 seconds to read all of the sensors. With these data they could make thermal maps of the mirror to look at what the temperature of the top plate was doing, what the bottom plate was doing or the air temperature. Since they were working on the mirror as a technology development project, these data helped greatly.


TOP
EXIT

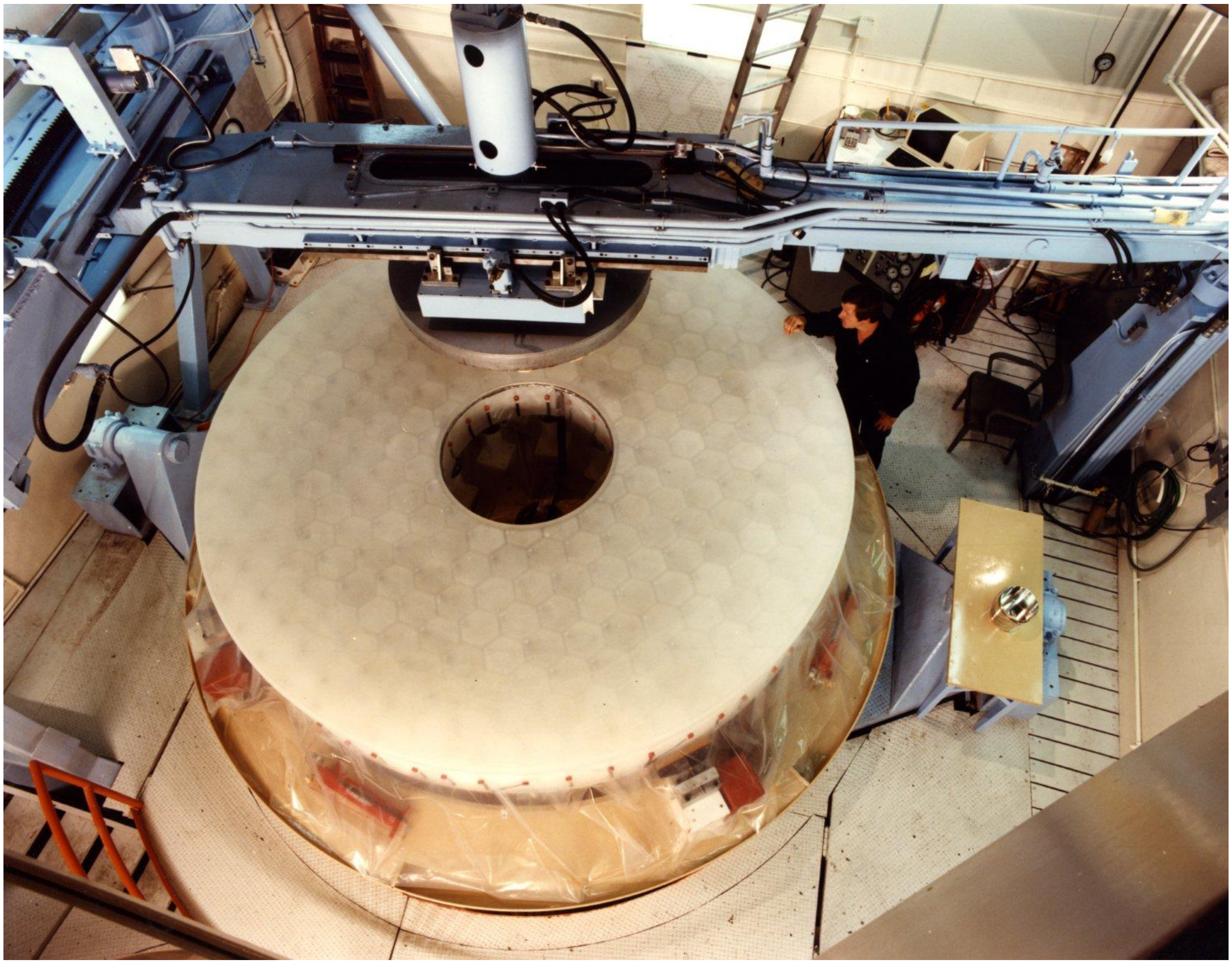
*Caption: Larry Junco down at the machine; Dave Dryden and Gary Poczulp reaching for the mirror*

**(00:51:36)**
Beginning of the installation of the mirror onto the polishing support. The mirror has been picked up off of the support stand, and with all of the wires bundled up out of the way, they are starting to lower it through the hatch. Right above Larry Junco one can see the exhaust fan and the ladder that leads to the emergency exit door.



*Caption: Left to right: Glen Pickens taking photos, Bob Harris, and John Richardson*

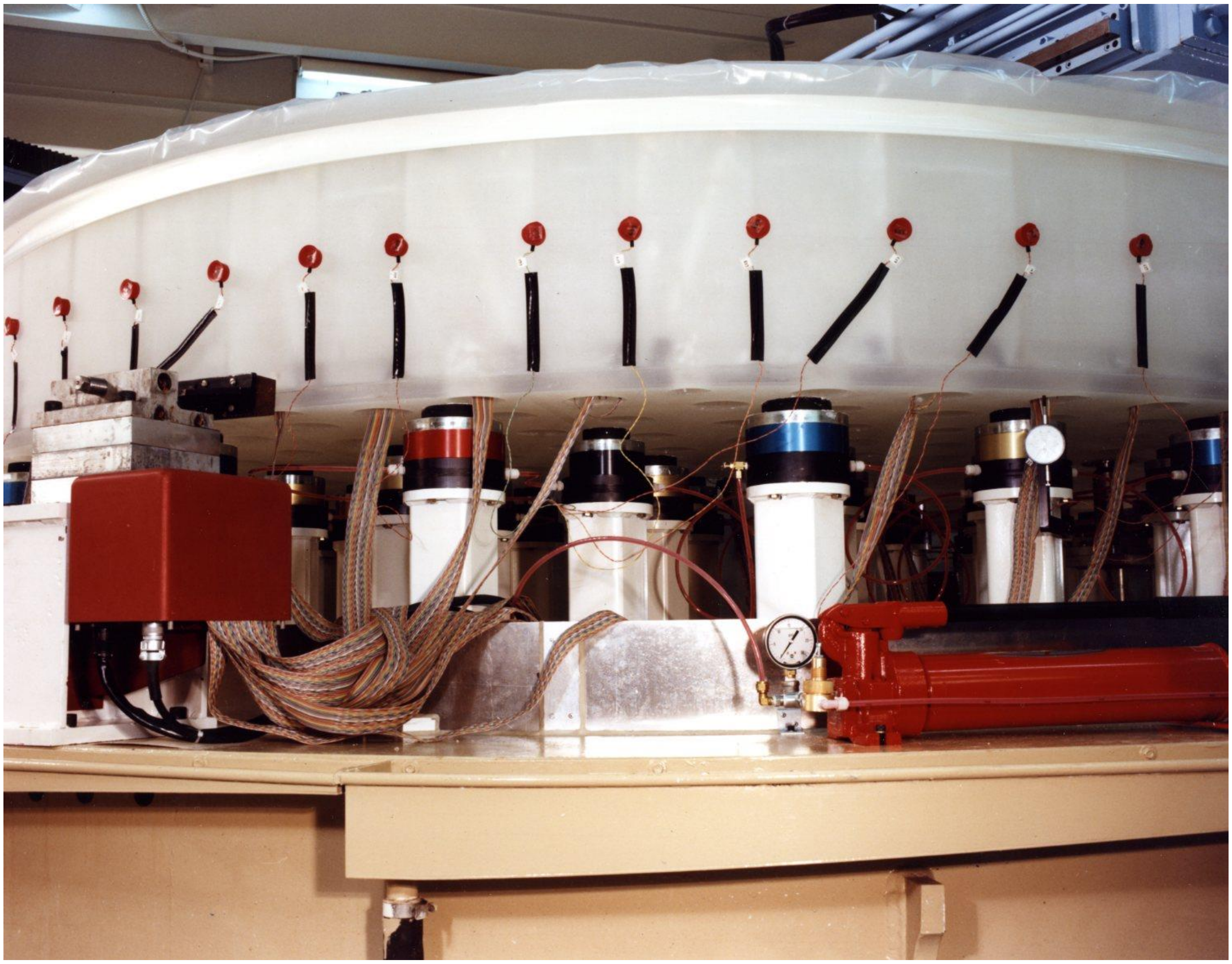
**(00:52:10)**
The label that looks like a mirror image is not because the photo has been reversed; it was written to be seen from the other side of the machine. This shows nicely the hydraulic polishing supports and the hydraulic fluid lines. The three points attached to the bottom of the mirror are rotation restraints to mate with three balls amidst the polishing supports. What look like black spots on the underside on the mirror are actually the black insulators on the thermal probes inside the cores.



*Caption: Gary Poczulp looking at the mirror surface*

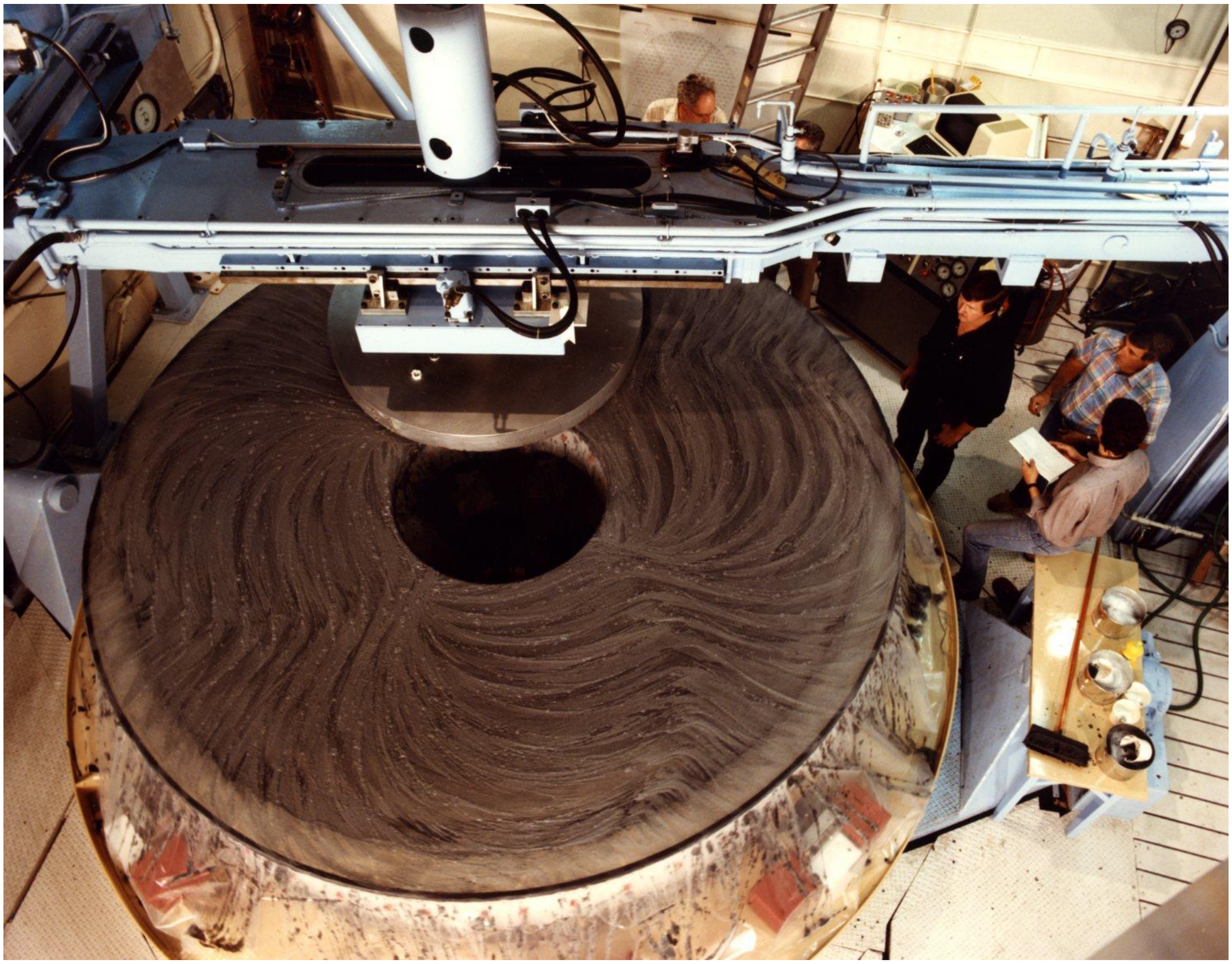
**(00:54:50)**
The mirror is now down on the table. The edge temperature sensors are visible on both the outside and inside diameters.

The grinding tool over the mirror is a special honeycombed (hence lightweight) grinding tool made for this project by an aircraft manufacturer located in Las Vegas {editorial note: Gary thought}, costing around $10,000. It is lightweight but very rigid and has been covered with a number of round ceramic tiles which were machined with opposite, convex, curvature that matches the 1.25m concave radius of curvature of the mirror. You then start off with a coarse grit. These are round, beveled tiles that require less attention due to the bevel. With straight-edged tiles bits of the sharp edges can break off and scratch the mirror surface. The tool is close to 1.8m in diameter. Note the plastic skirt around the outside edge to allow the water and grit to flow away from the electronics for the temperature sensors.



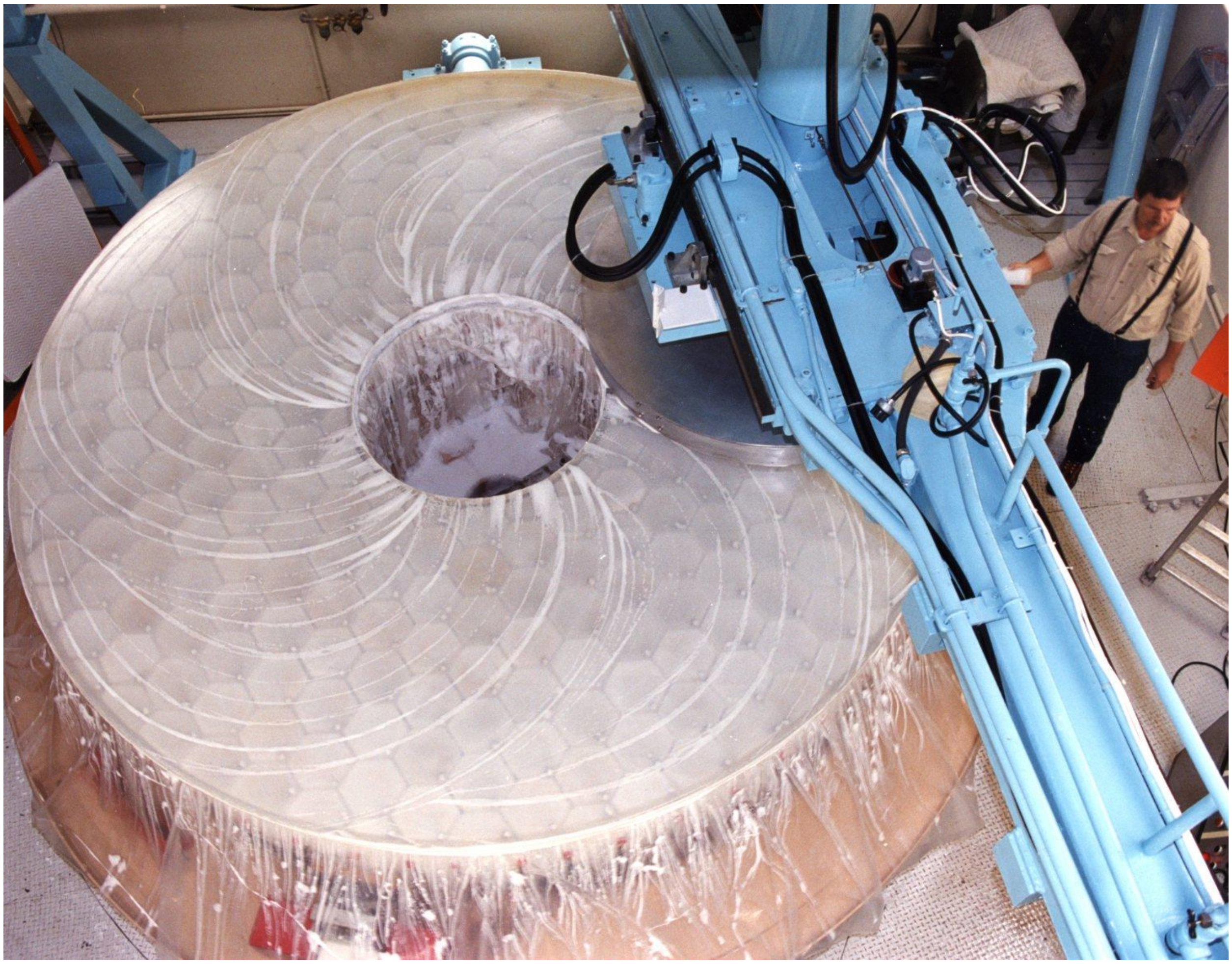
*Caption: A close-up of the edge and the temperature sensors*

**(00:58:42)**
The close-up with the skirt lifted shows the red covers that are over the temperature sensors that had been epoxied to the side of the mirror. These are located at the locations of the rib joints at the outer sidewall of the mirror. The wiring for these and the probe inside the cores are visible as well as some of the hydraulic lines going to the polishing supports. The supports have bellofram inside that position the pistons relative to the amount of force they will provide.



*Caption: Peeking up above the machine is John Richardson; Gary Poczulp is on the right, next to Dave Dryden, who is talking to summer student Mike Roman*.

**(00:59:22)**
The grinding with carborundum in process showing the grey colored slurry. The tool is in contact with the glass and is overhanging the center hole of the glass. On the table at right are several containers of grit as well as a mop. They would use plastic scoops for the grit, then add water plus soap, sling the mixture out on the mirror, and use the mop to spread it around the mirror surface. Both the tool and the mirror are rotating, and the tool can be moved both radially and laterally across the mirror as well as up and down to adjust the pressure.



*Caption: Similar view as above but showing aluminum oxide grit. Gary Poczulp is at the right.*

**01:01:20**

After two stages of grinding with the carborundum, before switching to a finer grit, the mirror has to be thoroughly cleaned to remove all of the larger size grit which would cause scratches that could endure right to the polishing stage. Gary is holding a squirt bottle of the $Al_2O_3$ — either 25 and 12 microns grit or possibly 40 and 25 micron. {editorial note: Gary kept notebooks containing daily notes documenting everything that was done to the mirror, especially while they were testing so that they knew what the data meant.}

*Caption: Left to right: Gary Poczulp (in suspenders) squirting aluminum oxide on the mirror; John Richardson standing in the back*

**(01:02:55)**
Continuation of the aluminum oxide phase of grinding. Gary is shown squirting the liquid grit mixture onto the surface. On the top of the tool can be see a PVC pipe into which some of this liquid grit mixture can be squirted. There is a hole in the middle of the tool for what comes out of the other end of the pipe to drip down onto the mirror from the center of the tool. This grinding phase will give the mirror its 12.5m radius of curvature.

*Caption: Gary Poczulp squirting the polishing material onto the mirror surface*

**(01:04:59)**
Into the polishing phase, indicated by the change of color of the slurry running off the side of the mirror, now a tan color, implying cerium oxide as the polishing compound. The grinding phase would use grits that would gradually get smaller, from 40 to 25 to 9 microns here. {editorial note: For smaller optics one can go down to 5 or 3 microns, i.e., each succeeding grit would be about half the size of the previous one. With large pieces like this mirror and the large tool, if too small grits are used the pieces can get stuck together.} The polishing compound is typically on the order of 2 microns {editorial note: Or smaller, depending on the material used}. The tool has also been modified with the tiles covered with pitch, which accepts the cerium oxide. {editorial note: In the old days iron oxide was used, but it is very messy and stains everything.} The polishing particles get imbedded in the pitch, which flows due to the temperature (it is initially warmed) and pressure so that it takes on the exact shape of the mirror. At this point the goal is to obtain a spherical surface, which is much easier to test than aspherical surfaces. Because they were developing certain techniques as well as the thermal effects and the

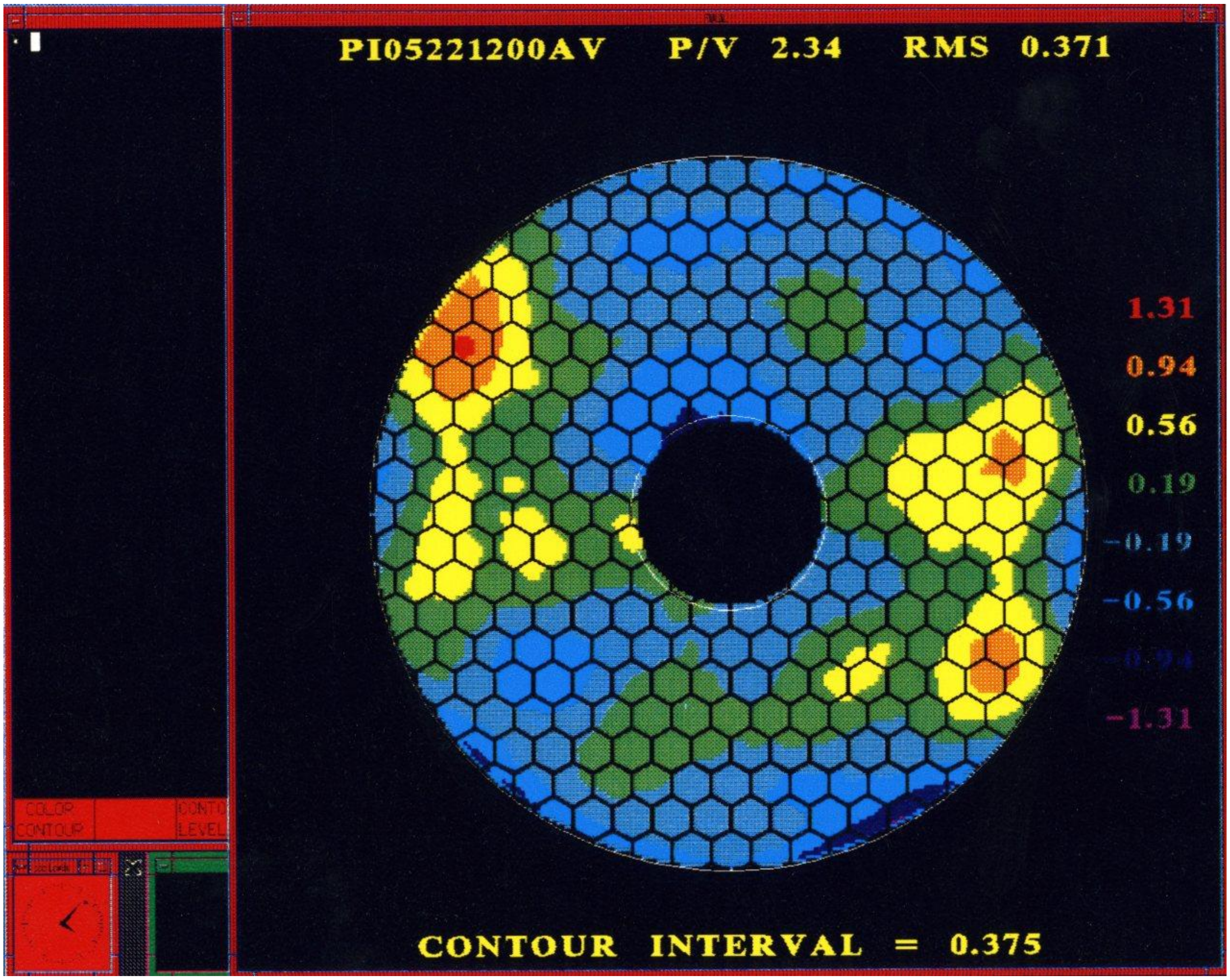
effects of the mirror support system, testing is much easier if one doesn't have to worry about aligning a null lens used for testing an aspherical surface. All of the testing of each new technique meant that it took longer than usual even for a mirror of this size – from the time they received the mirror until it was installed in the telescope was about five years. At lot of that time was taken up while doing these investigations of the new techniques, i.e., investigating the thermal and mechanical properties of the mirror.

During the initial polishing they would polish for 3-4 hours, squirting the polishing compound pretty much all of the time to make sure the surface did not dry out. You are also watching the machine to add some randomizing to the tool motion relative to the mirror. You want to avoid ending up with a synchronized pattern polished into the mirror surface, so controlling the machine by hand adds a natural randomization. Since the machine was hydraulically controlled, these stroke positions would drift with time, so occasionally you'd have to operate a bypass valve to reset the machine. As a result, they ended up with a nice (uniform) spherical surface.

This approach could be described as a sort of "old school" method. At the same time, the SO Mirror Lab was experimenting with new techniques, for example, the stress-lap technique, in which the polishing tool, called the lap, would be bent in real time. This permitted using a large tool to polish an aspheric surface because the lap is constantly being bent to match the desired shape according to its position on the mirror. This required a heavy dependence on computational techniques to control the lap.

The KPNO technique was old school, but adequate for achieving a spherical surface using a large, rigid tool. For the WIYN mirror the tool shown is about 1.8m. For the 4m mirrors (Mayall and Blanco) they used a tool that was about 3m across. After reaching the spherical shape they had polished in the asphere using smaller tools in zones. The smaller tools had to be more flexible to accommodate the curvature, which is always changing due to the asphere.

As they went into the polishing stage, they could see where the polishing was happening and would check the curvature value using a spherometer.



*Caption: Plot of the data output from a wavefront test*

**(01:15:20)**

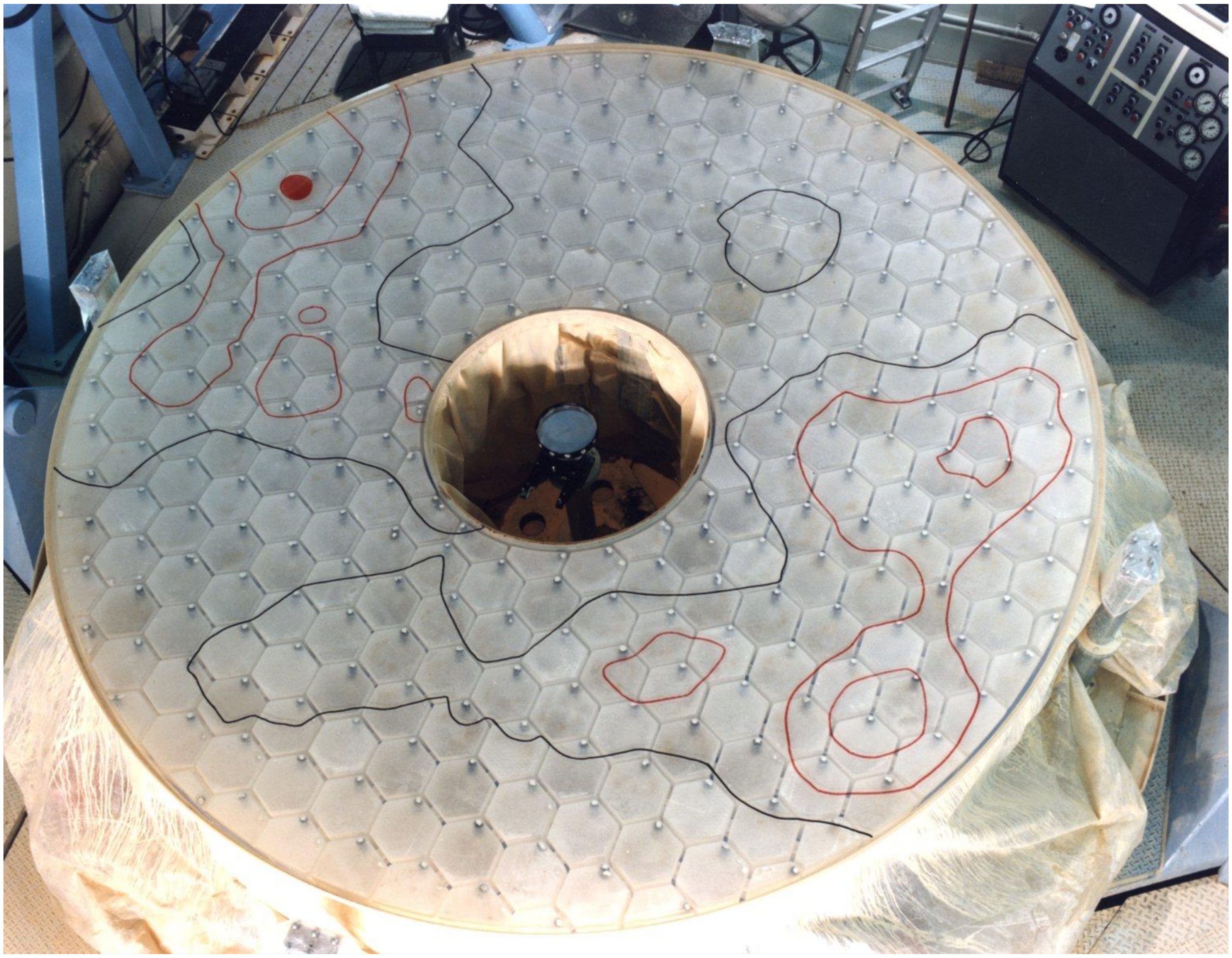
*Caption: Gary Poczulp on the mirror surface transferring the contours from the wavefront test*

**(01:15:30)**

Gary using the photo of the "hit map" using the hexagonal grid to match positions on the mirror. Marking with a magic marker will provide a guide to where the high spots are. In old school polishing you polish on the high spots, and if you do it appropriately enough the surface will improve. Then you iterate and do it again.

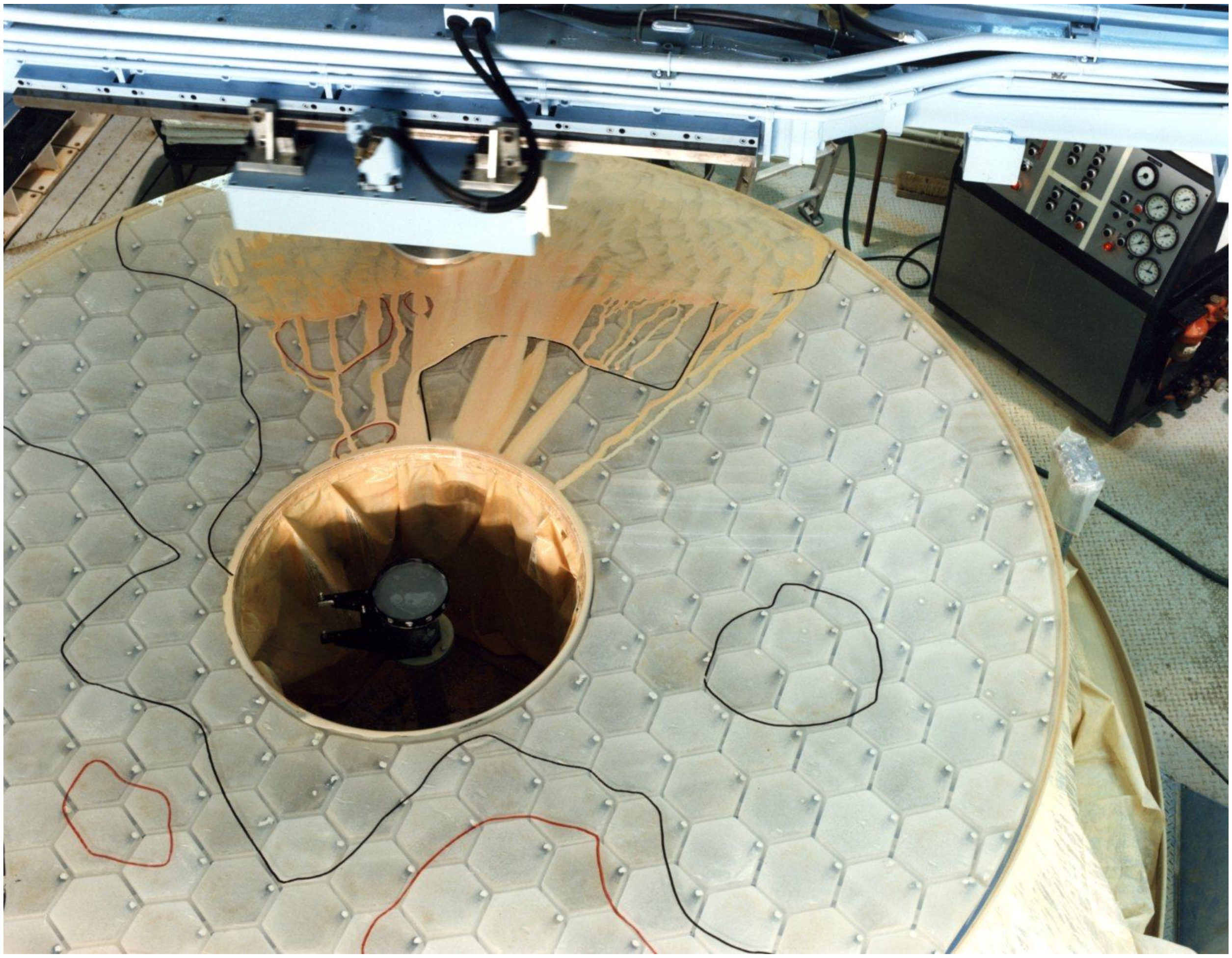
The white spots on the mirror are just the thermal grease used with the thermal probes inside each cell on the underside of the top plate.

In the center hole you can see a fixture onto which would be attached an auxiliary mirror to be used with the scatterplate interferometer called a common path interferometer. It uses a direct beam, a scattered beam, a scatter-direct, and a direct-scatter. The scatter beam and scatter-direct beam interfere to give fringes. A disadvantage of this technique is that part of the laser beam produces a hot spot that blinds the detector. They decided to use the auxiliary mirror with the same radius of curvature in the center hole to accept the direct beam.



*Caption: Mirror, once the transfer of the wavefront map is complete*

**(01:19:25)**
This photo shows the whole mirror once all of the map of wavefront errors is transferred, showing a dog bone-like region on the right side and a hot spot on the upper left. The red areas show where Gary would be spending time with smaller tools—a 16 inch diameter tool and a 24 inch diameter tool. They made estimates of how long it would take to make corrections, then adjust the position and shorten the stroke of the Pitman arm. They would work on one area at a time trying to more or less stay within the lines, allowing for a bit of randomization. This was also a very iterative process. This is called the figuring part (after the grinding and polishing parts), once the polishing has removed the subsurface damage. So this is making the final adjustments to the shape of the mirror, wearing down those high spots and making the surface more spherical.

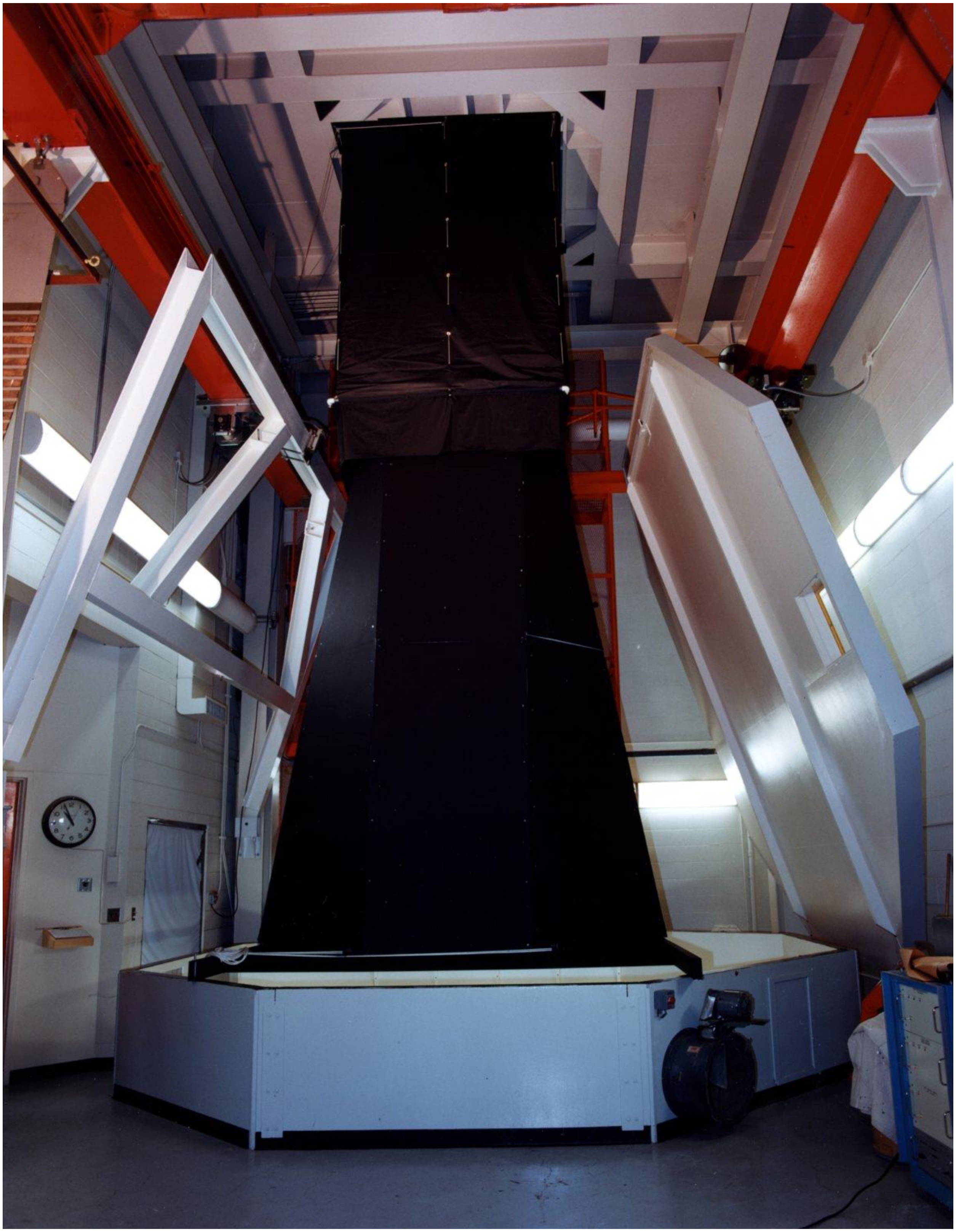


*Caption: A small tool is being used to remove one of the high spots*

**(01:21:19)**
The machine is being driven so that the small tool can remove a high spot. The excess cerium oxide slurry is seen running towards the center hole. The tan slurry on the surface at upper right shows that the machine hasn't gone outside the contour lines too much. For this step the table carrying the mirror is only rotating through very small arcs before reversing direction. The rotating tool is being moved with the Pitman arm over the high spot. {editorial note: For full aperture polishing the table would be turning constantly, only reversing direction occasionally. Since the motions were hydraulically controlled, stopping the mirror meant waiting for it to coast almost to a stop before hitting the change direction button.} Working on each spot would take the better part of a day, then the table would be rotated to bring the next high spot to where the tool could work on it. There was no computer control of the positioning, since this machine dates from the 1970s. The small tool would never touch the regions outside the contour lines that were at the nominal radius of curvature surface. You would normally try to remove all of the high spots before retesting the mirror. Sometimes they would have to go back

to the large tool and do a smoothing run if some regions were not a proper fit. The polishing of the high regions would be done cautiously, since you didn't want to remove too much, since the low spots would then become new high spots.

Just visible at the right side, just outside of the outer edge of the mirror, is a vertical stand that has six tooling balls. These were used to define different positions of the Hartmann mask for testing using a CCD detector over quadrants. By shifting the Hartmann screen to a different set of tooling balls the test would sample a different part of the mirror to get a smoother map.

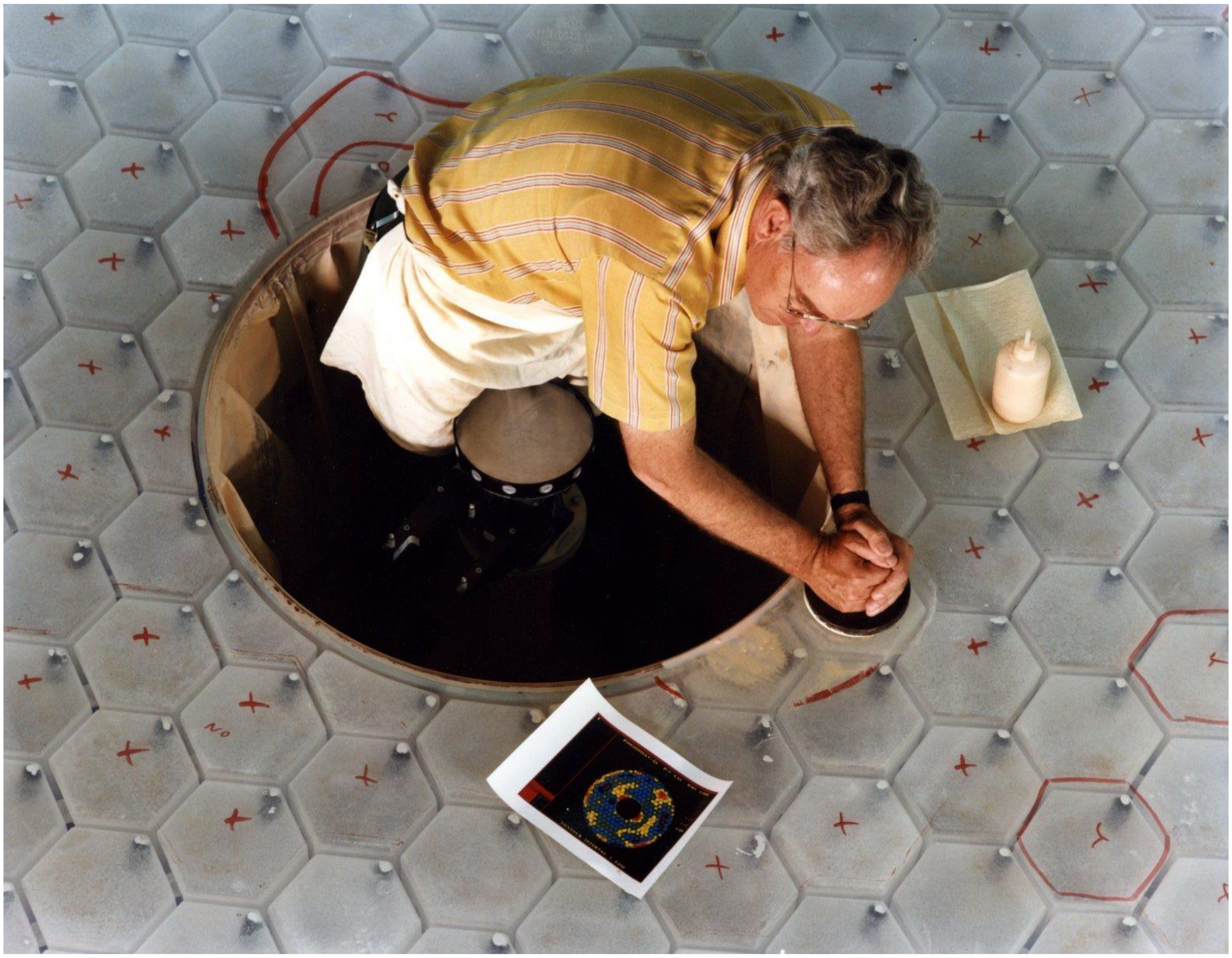


*Caption: A view of the shroud for testing the mirror*

**(01:27:18)**
A view of the shroud in the test tower with the hatch open. This has multiple sections: the first, at the top extending down from the crane rail, is made of fabric, extending down to about the top of the hatch; below that is a section made up of black painted Styrofoam sheets attached to a metal frame resting on the top of the hatch. Inside of that is a cloth curtain that extends down to the level of the mirror.

*Caption: Left to right: John Richardson, Myung Cho, and Gary Poczulp*

**(01:28:23)**
The cloth curtain that extends down from the top of the hatch and extends out to the outside edge of the mirror, being lowered and positioned. This assembly totally enclosed the light path of the test setup to reduce turbulence that would interfere with the test results. The test instrument would be located 12.8 [12.5] meters above the mirror in the top of the test tower. Where they needed to locate the test optics, there was nothing, so a platform had to be constructed at the proper location. To access the test equipment, they needed to go up to the top of the test tower then climb down a ladder to get to the level of the optical bench that was resting on the building girders. There was a trash can with the bottom cut out to prevent anything from the test area from falling into the hole and down onto the mirror. One has to be very careful working above a mirror like this not to drop anything. {editorial note: There is a famous story of someone working at Optical Sciences when they were doing the Dupont [101” diameter] mirror dropped a crescent wrench, but it went through the center hole, missing the front surface.}

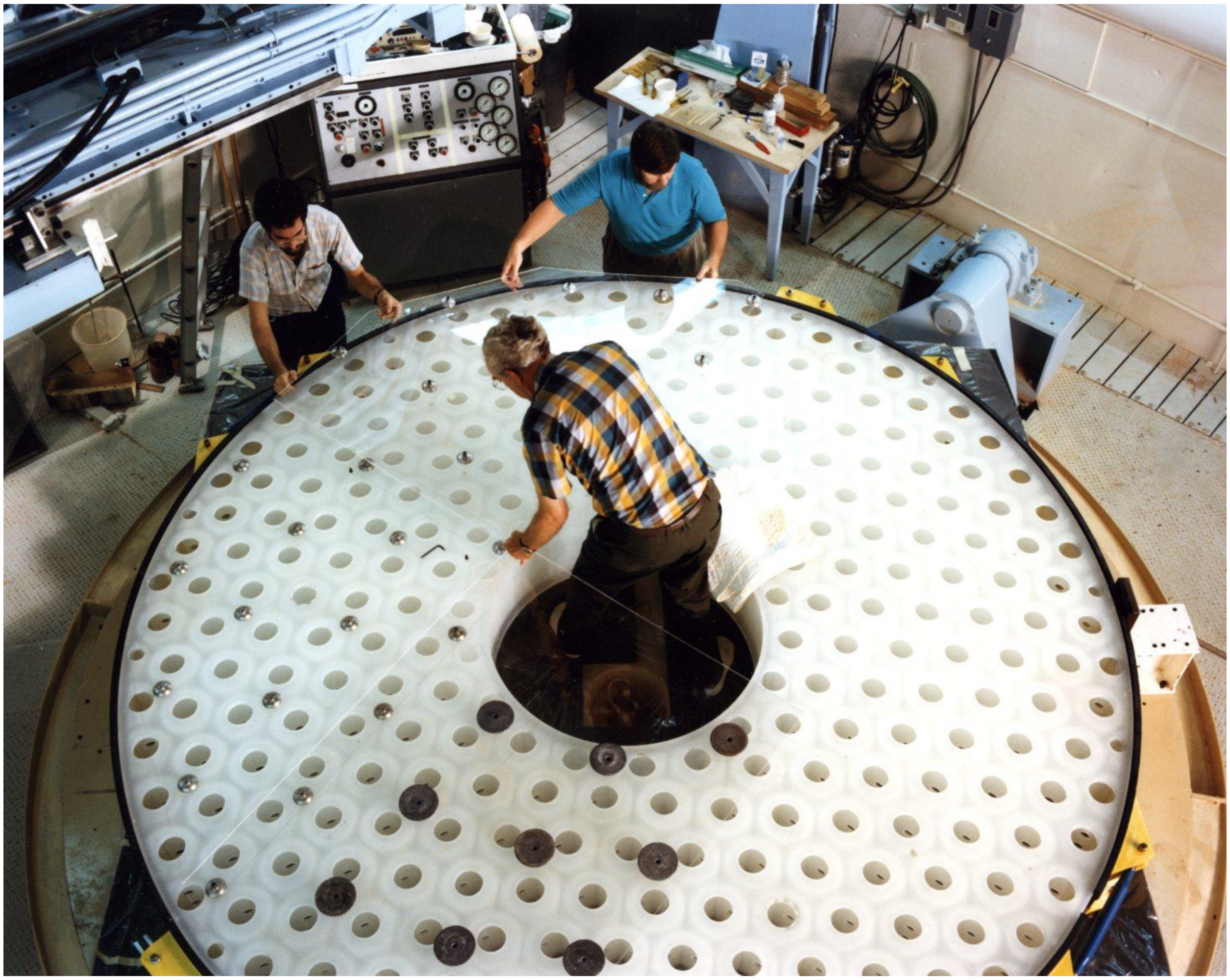


*Caption: John Richardson*

**(01:32:48)**
John Richardson is standing in the center hole using one of the "hit maps," which has been filtered to remove the low spatial frequency errors to show the high spatial frequency errors. The cores have been labeled with x's and y's to mark the highest areas. Richardson is working to remove what is called a quilting effect, which is caused by the surface over the unsupported areas of the cores being depressed by the tool pressure and therefore not getting polished like the walls of the cores. The latter turned out to be between 30–40 nanometers high. To remove these he took the 6-inch tool shown, covered it with pitch, then took it to a postal scale and held to apply what he thought would be a reasonable polishing pressure and measured it. He found that he was applying about a one psi of pressure, which is a little high for normal polishing. They found that they could remove one nanometer of height per second at one psi. On some areas he would polish for 30 seconds, some for 20 seconds, and so on. 30 nanometers is less than 1/10 the wavelength of light. The final figure turned out to have about 15 nm rms errors over the entire surface, so this technique worked very well,

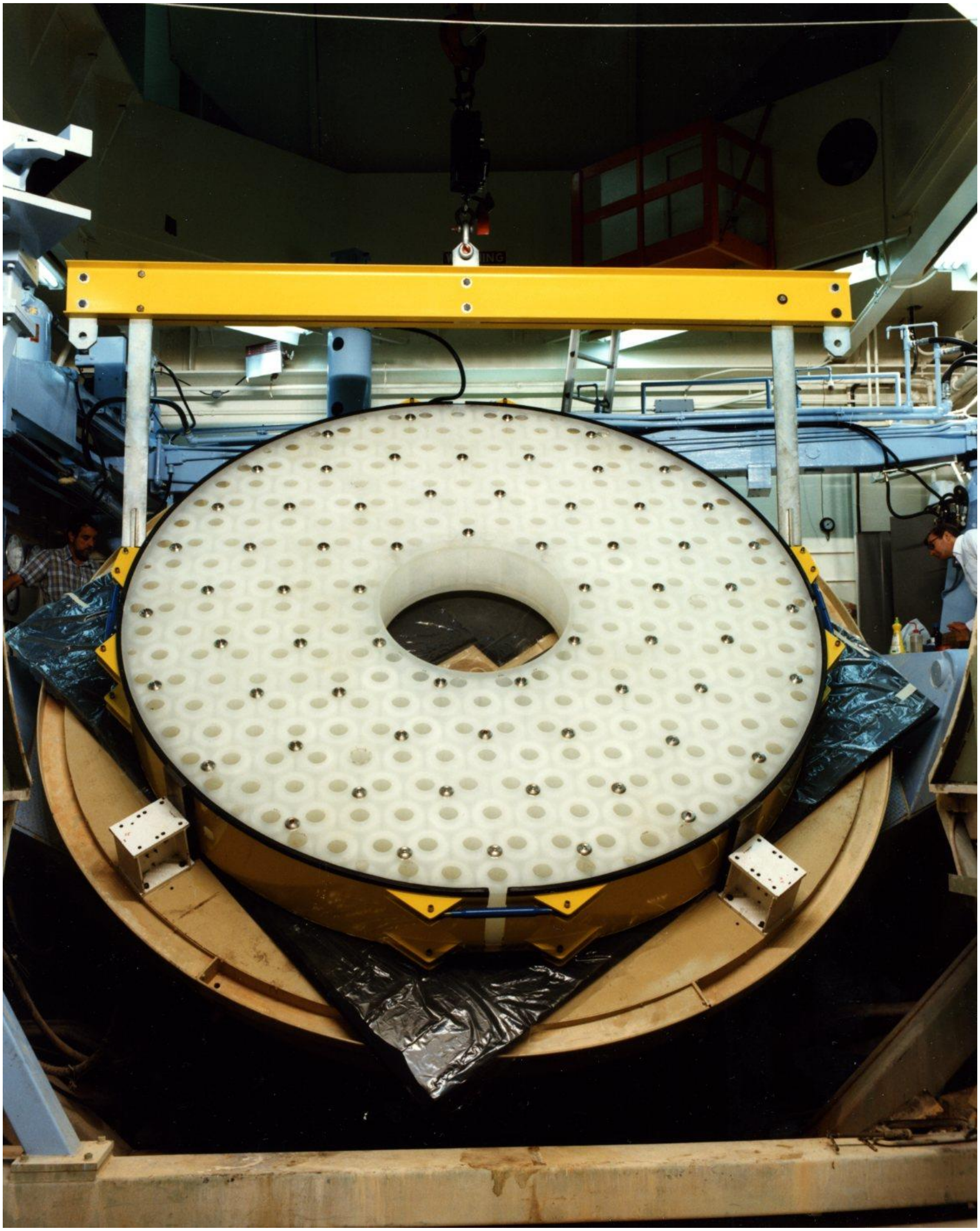
even though it was fairly labor intensive. [The requirements for the figure allowed more low spatial frequency errors than high spatial frequency errors.]

They [we] found [~~at the Mirror Lab~~] that if ~~they~~ [we] sealed the back side of the mirror and applied increased air pressure, that increased pressure kept the unsupported surface areas from being pushed downward by the tool, hence there would be no quilting effect. The Mirror Lab still uses ~~that~~ [this] technique on structured mirrors. The pressure on the mirror during normal polishing is about 0.1 psi.



*Caption: Summer Assistant {editorial note: name unknown} and Gary Poczulp at top; John Richardson in the center hole*

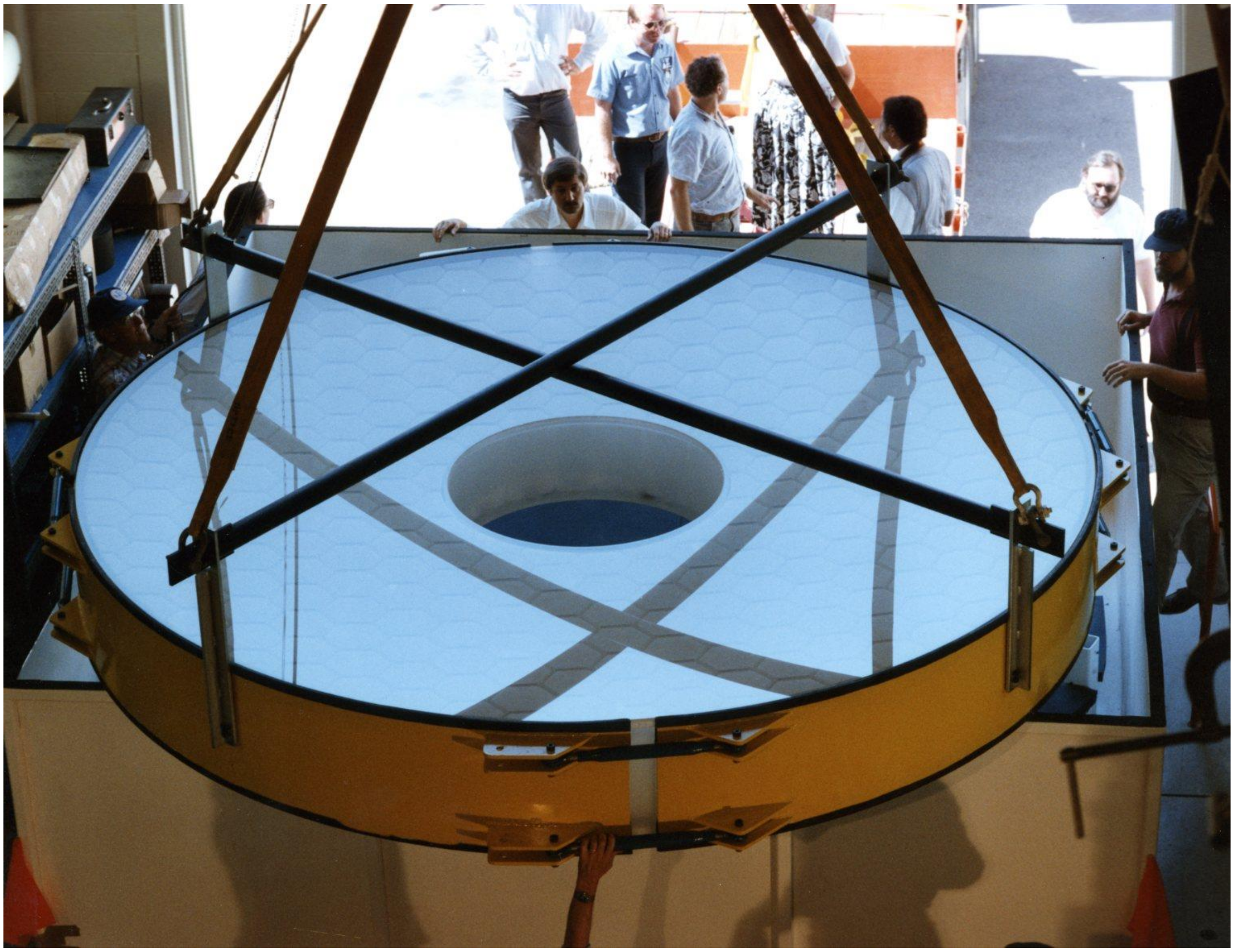
**(01:42:03)**
The team is positioning a plexiglass template used to define the positions of the Inva "pucks" that are being epoxied on the backside of the mirror for the 66 active axial support actuators. In the lower part of the picture there are several lead weights that had been placed over some of the Invar picks while the epoxy sets. At this point the front surface had been polished and the thermal sensors removed from all of the cores.



*Caption: Dave Dryden on the left; Larry Stepp on the right. The mirror tipped at about a 45-degree angle.*

**(01:45:44)**
The mirror in its handling band, tipped at about 45 degrees and supported by the crane, showing all of the support points in place. They are preparing to tip the mirror up to turn it around. The mirror was being readied to send it to Kitt Peak to be aluminized. They wanted the mirror surface to have the same emissivity as it would be in operation.

*Caption: The mirror being removed from the table*

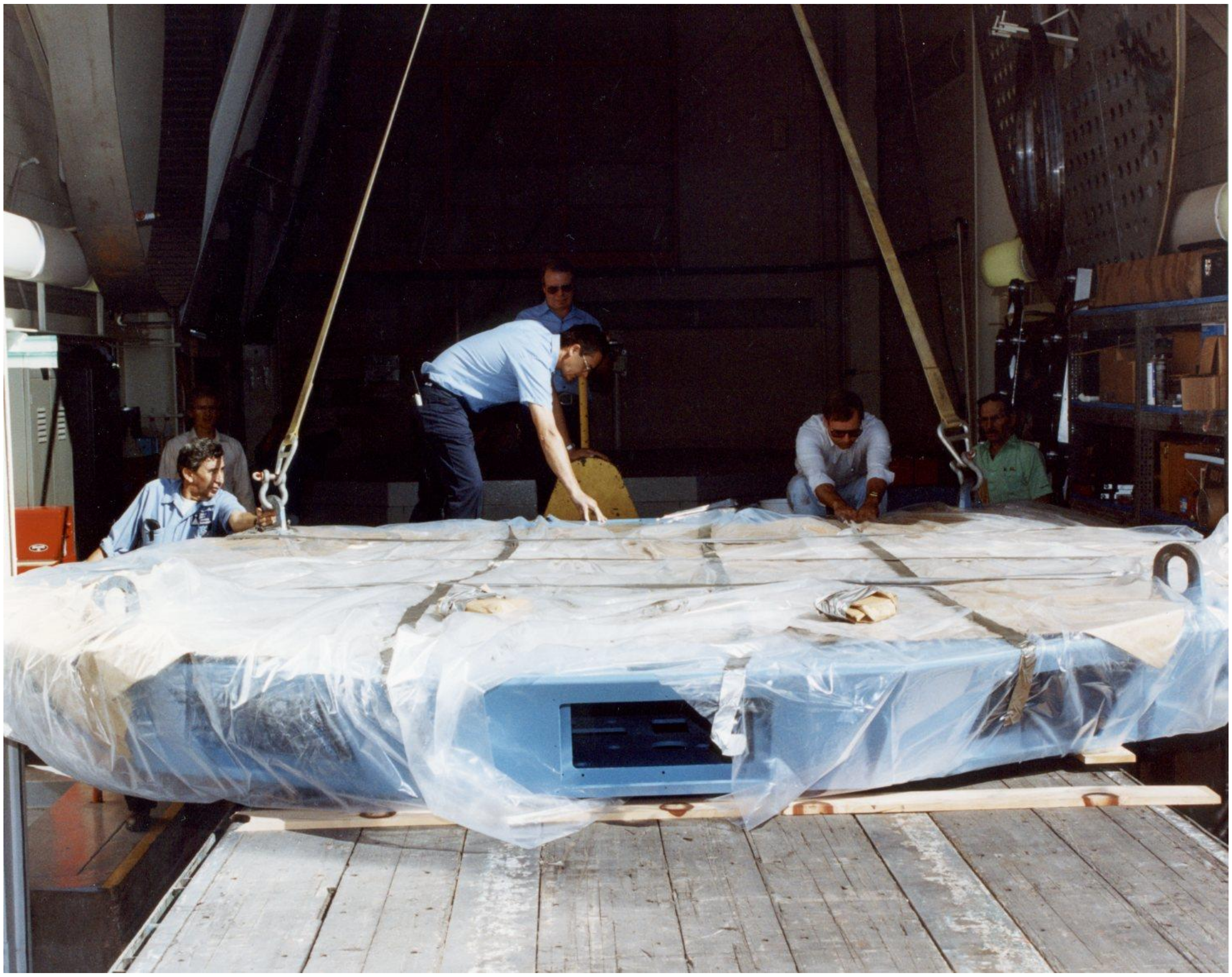


*Caption: John Richardson on left; Lee McComber in the center; Gary Polczulp on right side of crate*

**(01:46:48)**
The mirror being moved into its shipping crate for transport to Kitt Peak to be aluminized.

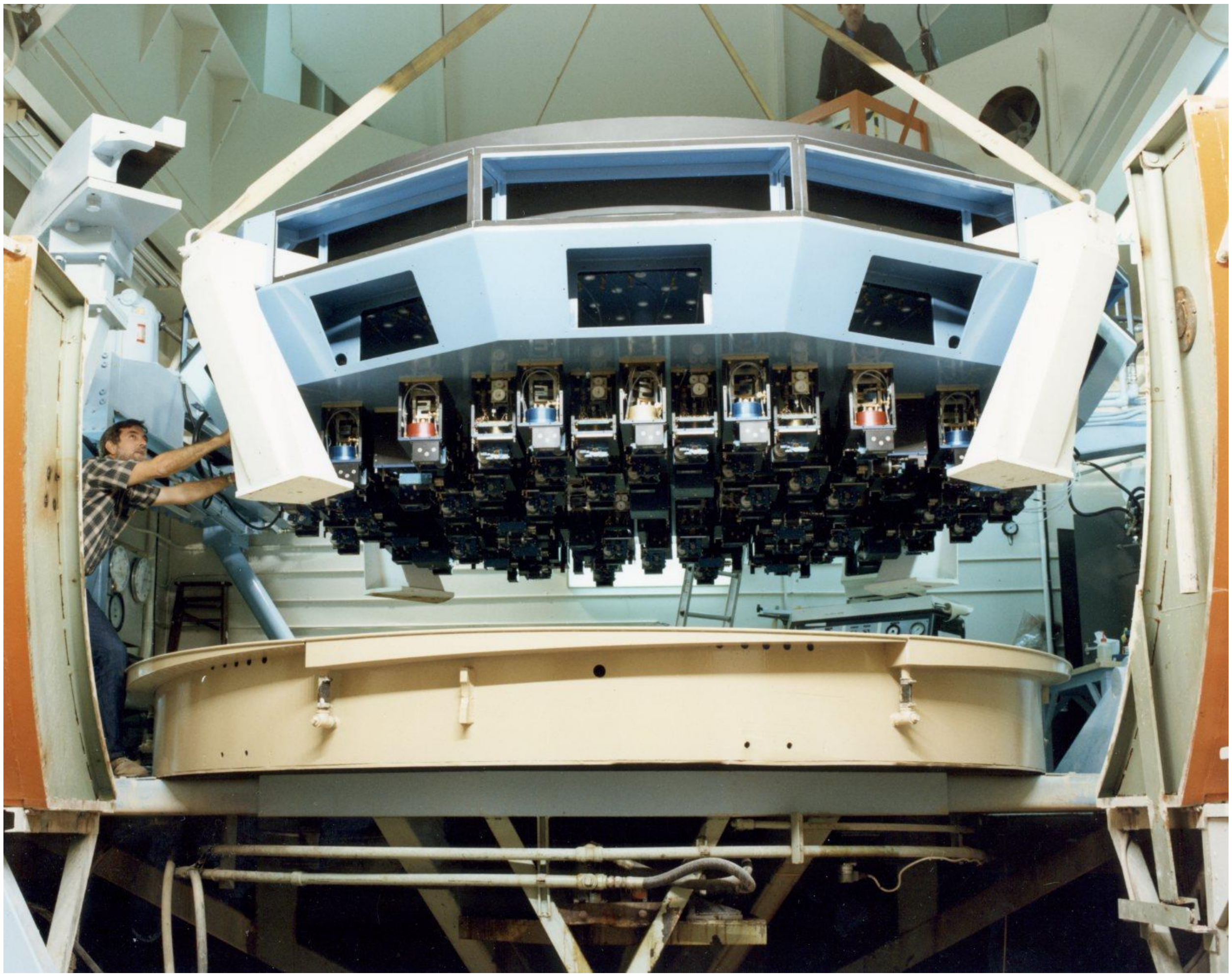
*Caption: Larry Stepp and Dave Dryden detaching cables from the hydraset suspended from the crane*

**(01:47:39)**
The mirror is in the crate, which is sitting on a truck that has been backed into the loading bay where the floor was pulled out to provide access.



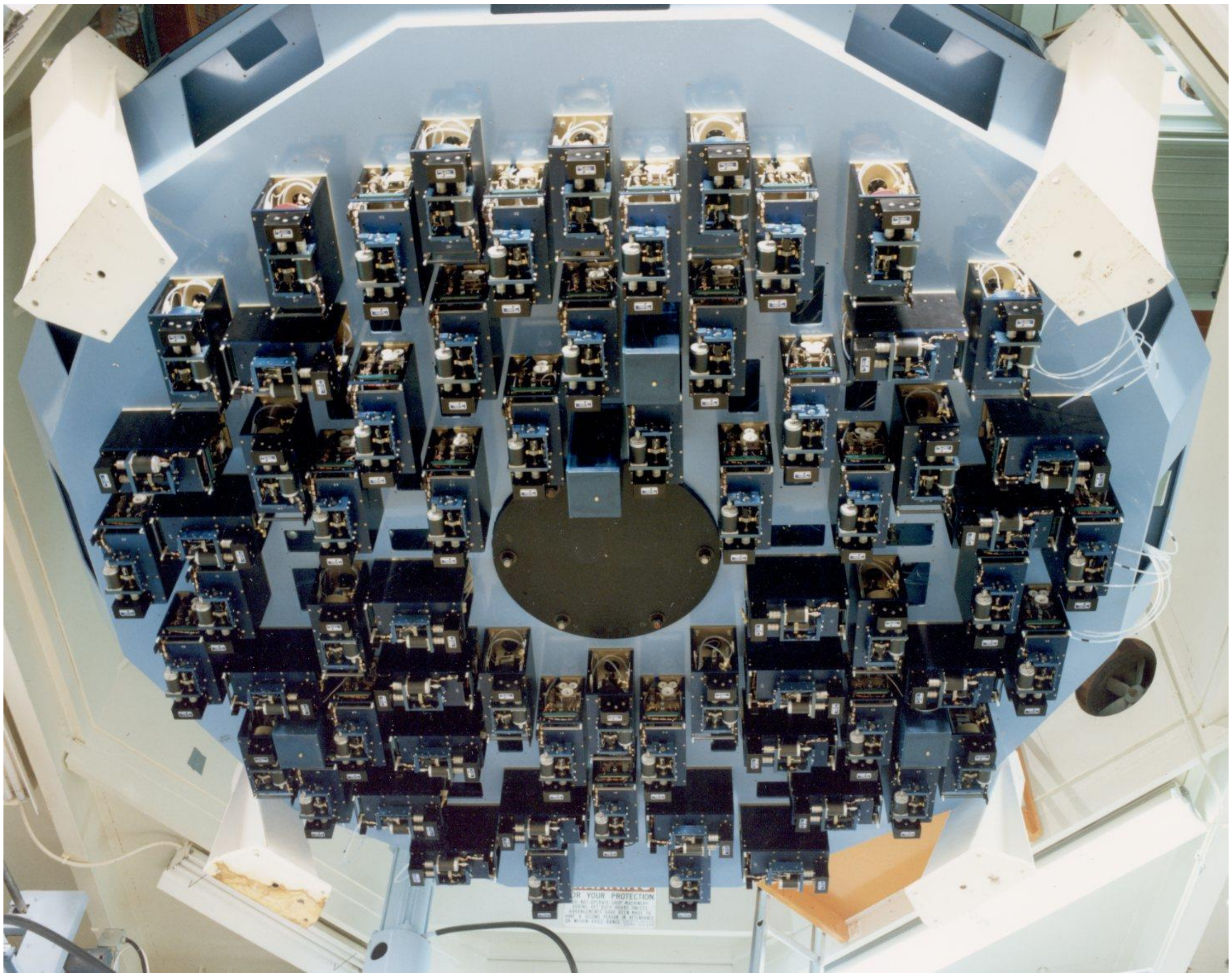
*Caption: TBD*

**(01:48:19)**
The actual mirror cell for the telescope being received at the shop. Next, the first generation of actuator supports would be installed as well as the thermal control system. The mirror would be installed and the entire assembly would be put on the polishing table for testing. Because the table can be tipped, they could do optical testing at non-zenith pointing elevations as well while variations of the mechanical mounting controls and thermal control of the mirror. Carrying out these tests downtown led to a more rapid commissioning of the telescope at the mountain.



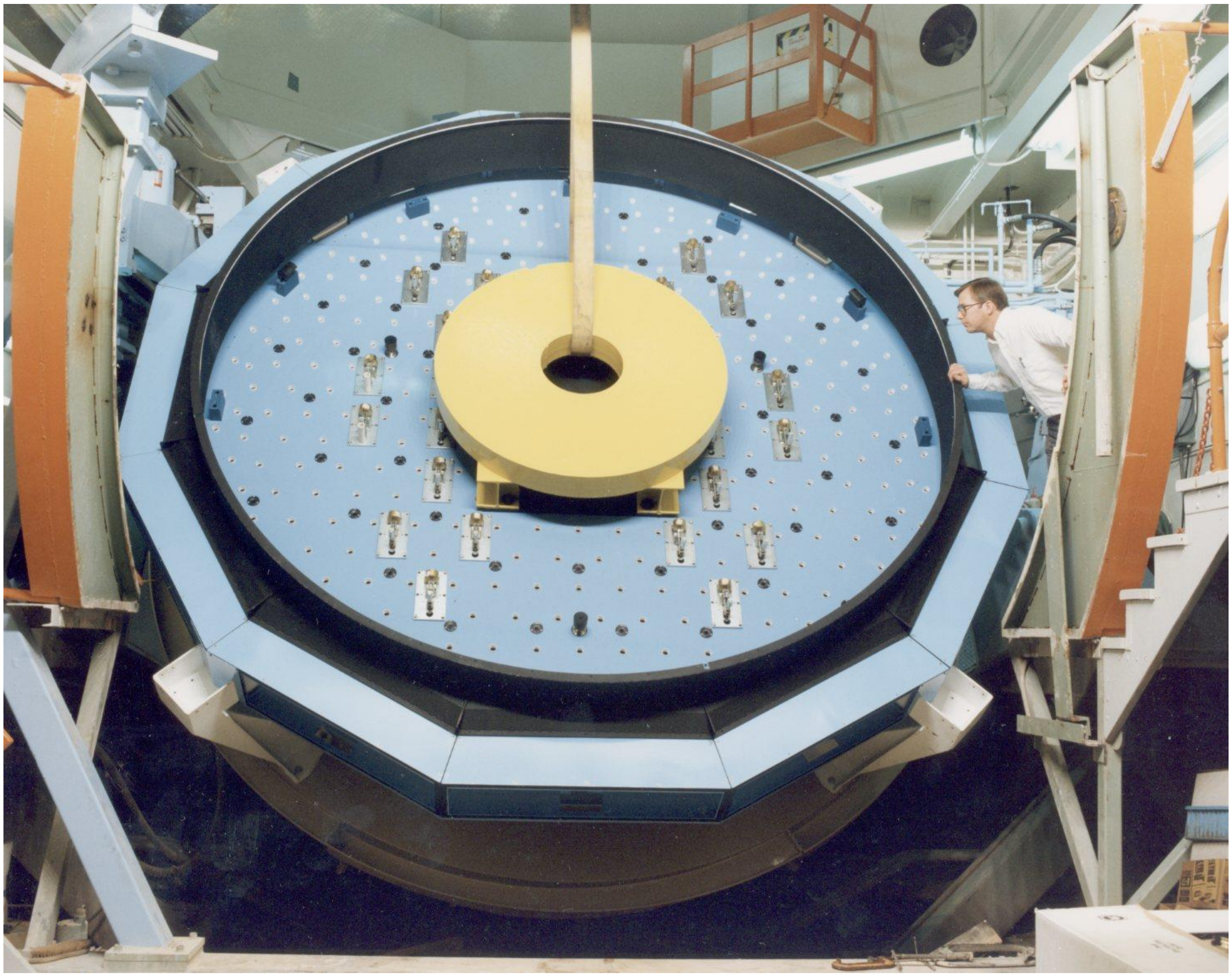
*Caption: Dave Dryden guiding the cell as it is placed on the table*

**(01:49:37)**
The cell with the first generation axial support actuators installed. The four white steel "sevens" (weighing several hundred pounds each) around the cell were to interface the cell to the table.



*Caption: Bottom of the cell with the axial active support actuators installed*

**(01:50:49)**
Bottom view of the active support actuator controllers, each of which had several panels that needed to be removed to access anything inside.



*Caption: Larry Stepp watching a disk being placed in the cell*

**(01:51:08)**
The circular steel disk that approximates the weight of the mirror being lowered into the cell. This had been borrowed from Apache Point Observatory, which had an identical mirror. This was used to verify that the machine could handle the over-turning moment on the polishing table when they went from zenith pointing to horizon pointing, since the weight of the cell plus mirror was some distance above the tipping axis of the table. There were no problems with this setup.

The lateral support mechanisms for the mirror are visible on the cell.

*Caption: Gary Polczulp and John Richardson next to the mirror on Kitt Peak next to the aluminizing chamber*

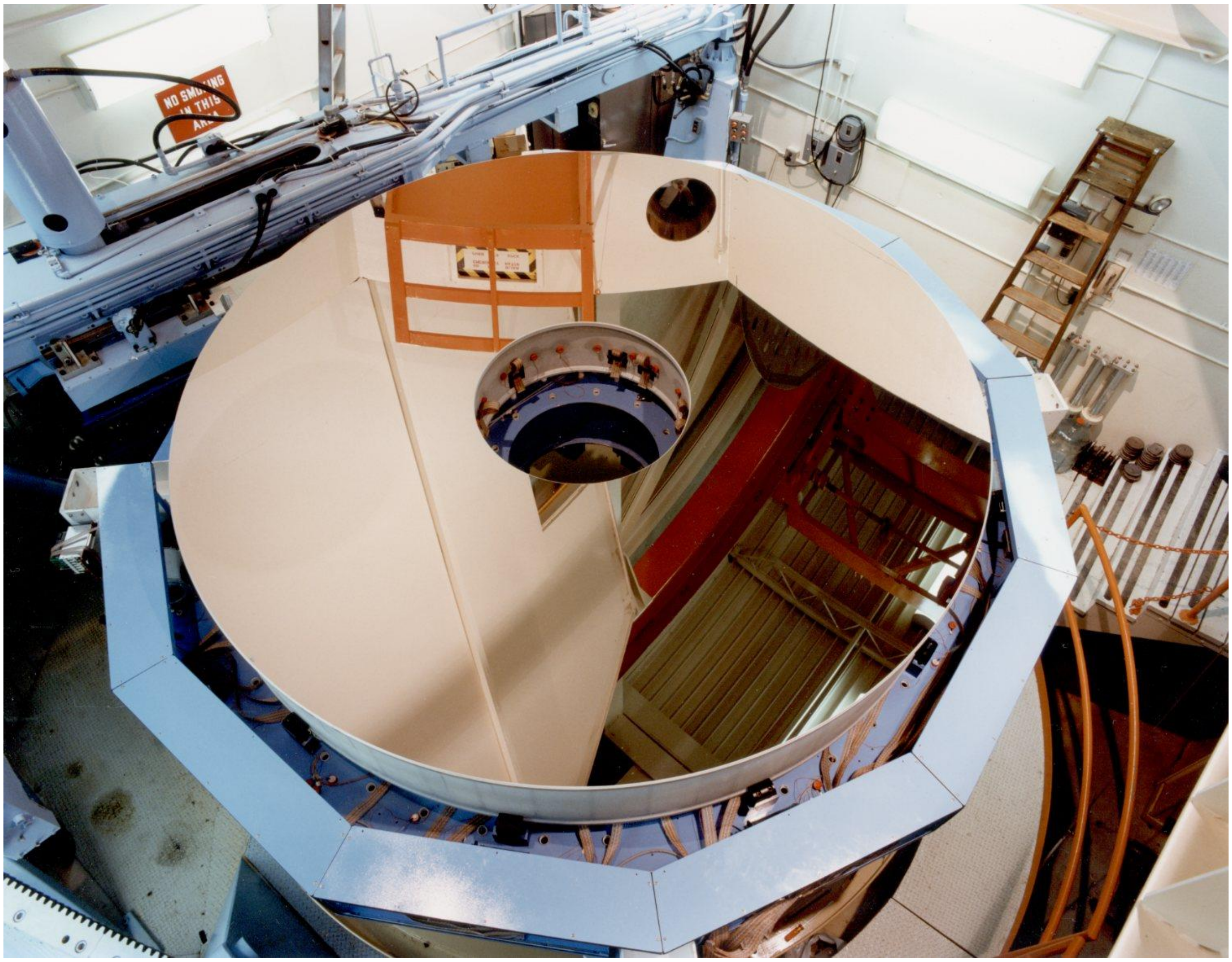
**(01:52:50)**
Inspecting the mirror after it was removed from the aluminizing chamber in the 4m building at Kitt Peak. At this point the surface figure was a sphere, not aspherized. This was done so for tests on how to optimize the active supports and the thermal control system, since they would do these tests both at zenith pointing and horizon pointing.

*Caption: Gary Polczulp on the left; John Richardson on the right, inspecting the coating*

**(01:54:40)**
A close-up of Gary Polczulp and John Richardson inspecting the mirror coating after being aluminized in the 4m coating chamber.

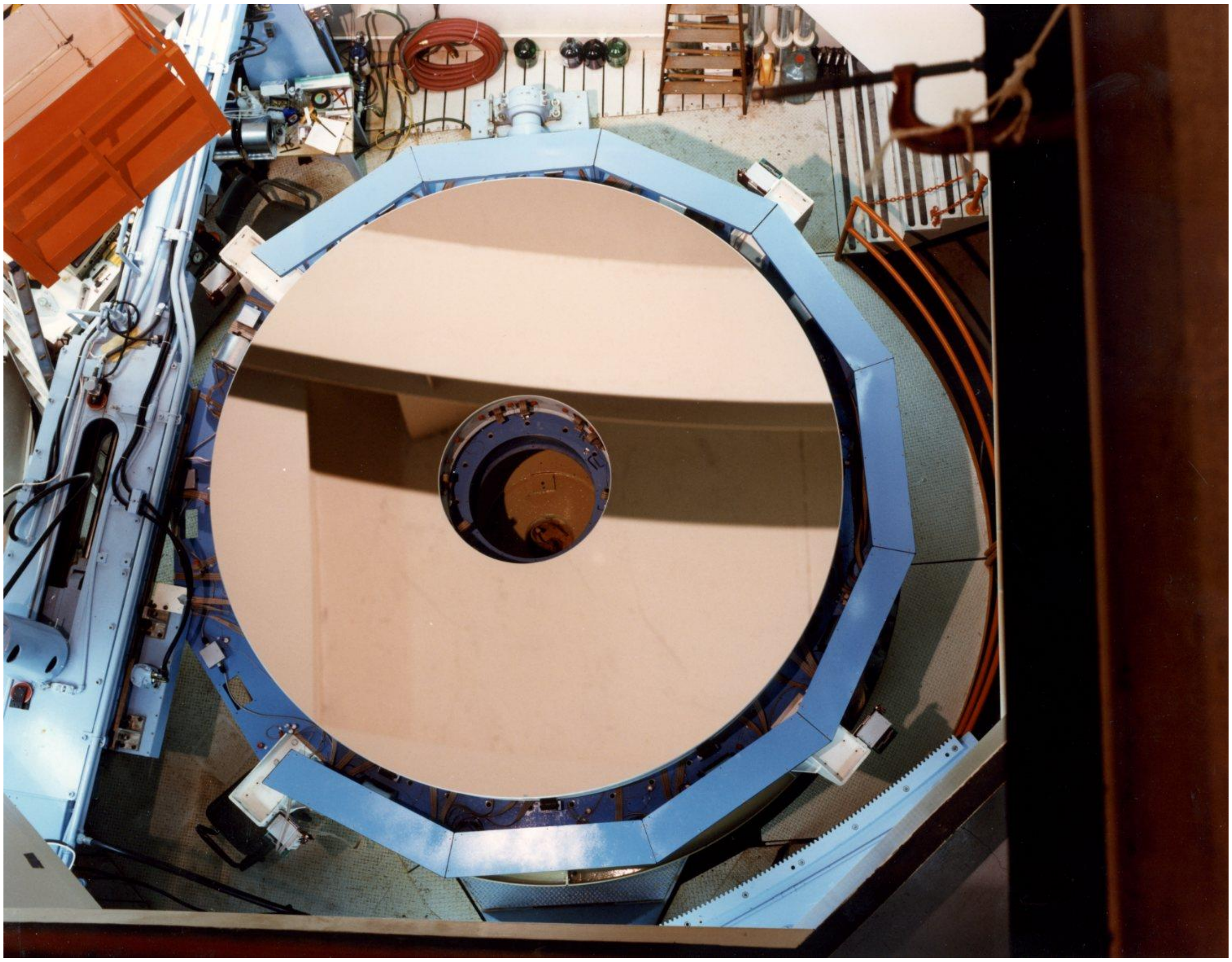
*Caption: Dave Dryden, center; Gary Polczulp to his right; Frank Vaughn to Gary's right; Jerry Valero at upper right*

**(01:54:51)**
The mirror in its shipping crate after returning from being aluminized at Kitt Peak. This was happening later in the day than planned, just before the sun would have been hitting the mirror and possibly focusing on a spot on the wall close to where there was a window into Tony Abraham's office. The cover for the crate is being lifted off the crate at the top of the photo.

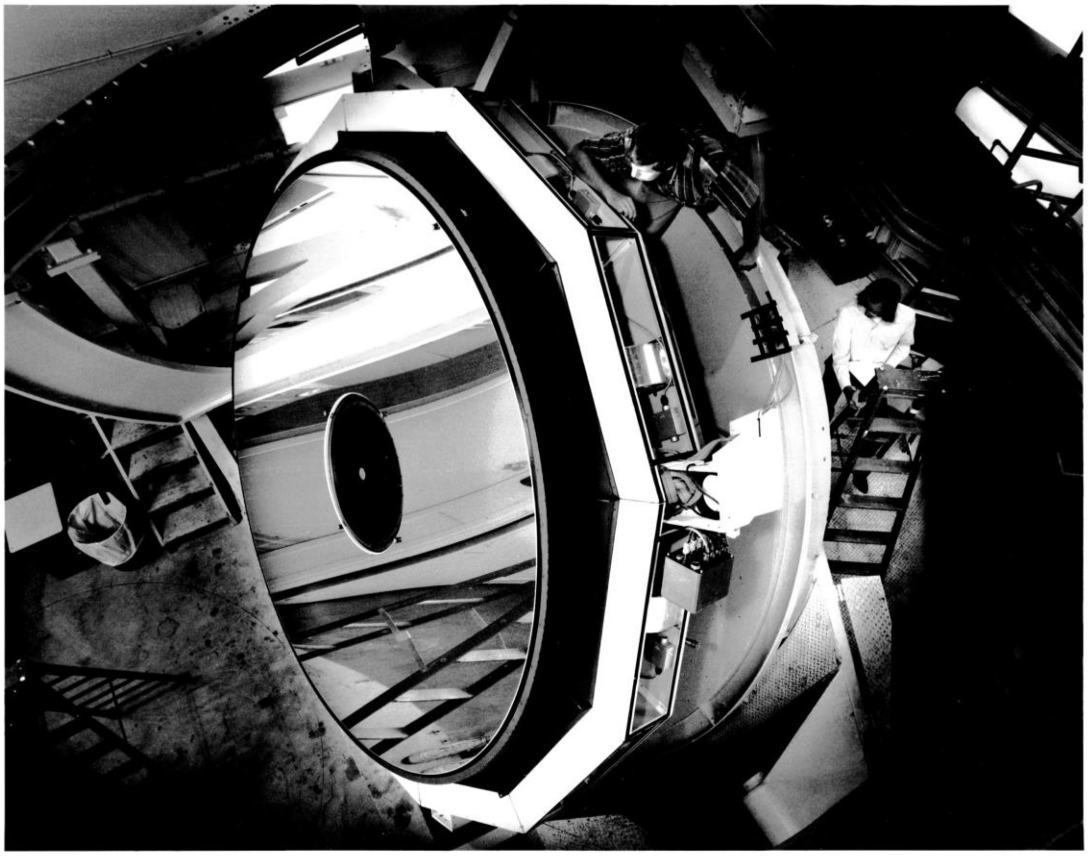


*Caption: The WIYN mirror in its cell on top of the polishing table*

**(01:57:03)**
The mirror in its cell on the polishing table after being aluminized. The cables for the thermal measurements had been installed after the thermal sensors had been reinstalled. No sensors around the outside edge of the mirror are in place, but several can be seen around the inside of the central hole.



*Caption: Another view from above of the mirror in its cell*

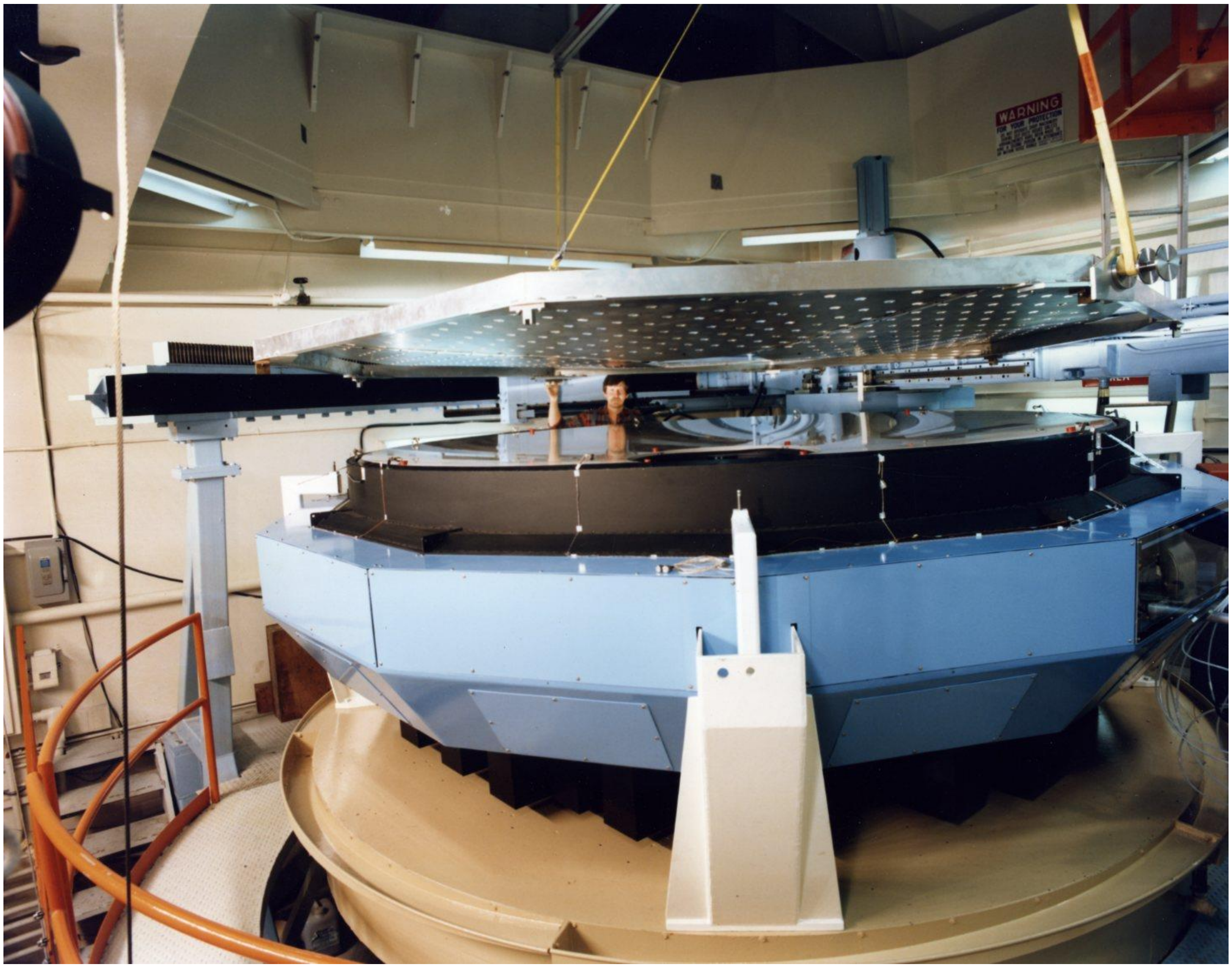


*Caption: Gary Polczulp is on the table looking into one of the plenums; Larry Goble on the right on a ladder*

**(01:58:30)**
A black and white photo showing the mirror tipped towards horizon pointing. The plenums on the cell are seen open, showing where the twelve squirrel cage fans are located. The temperature-controlled air from these is directed under the backside of the mirror and into the 296 open cores of the mirror.

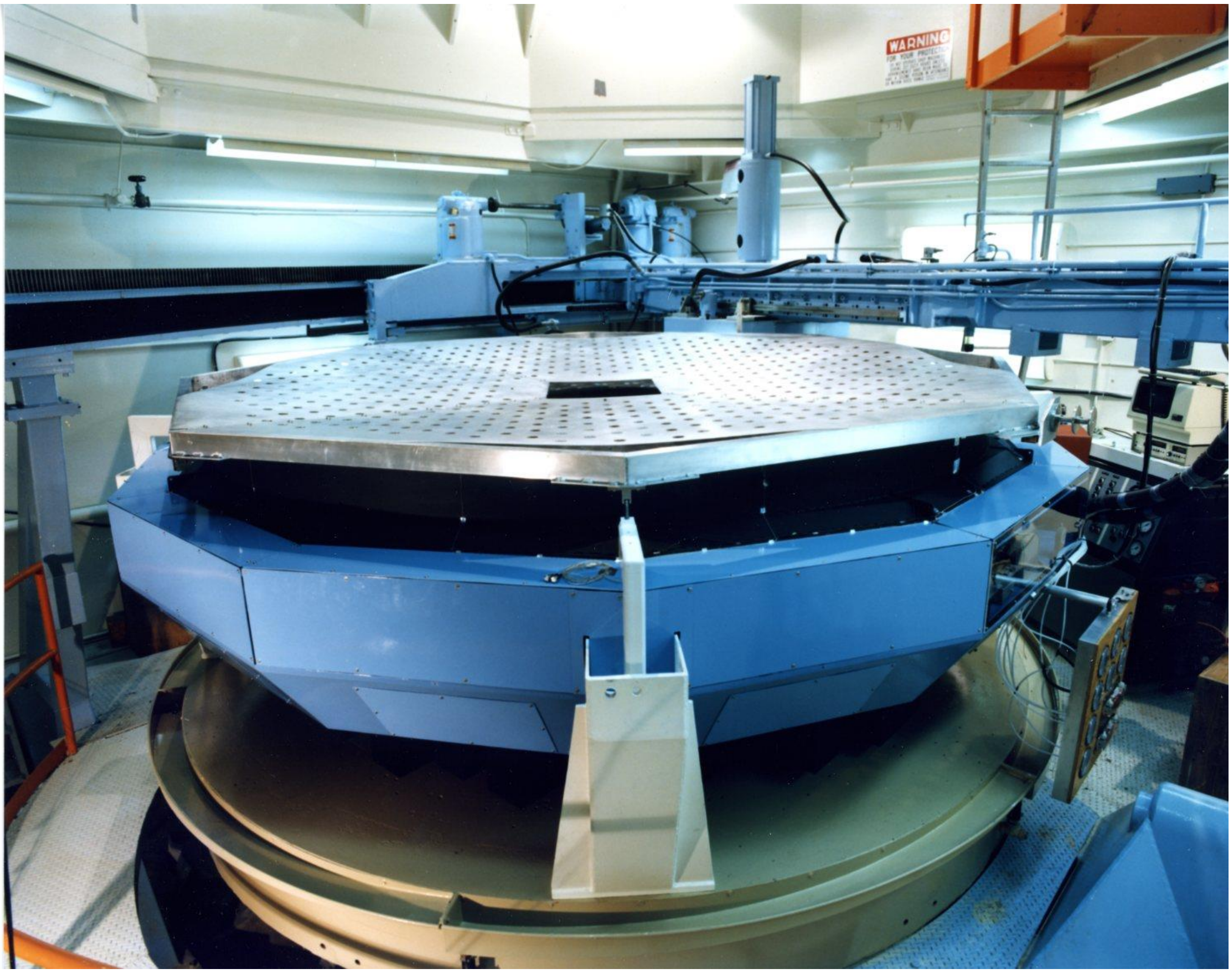
*Caption: Gary Polczulp guiding the Hartmann screen over the mirror*

**(01:58:30)**
In preparation for testing, the Hartmann screen is being positioned over the mirror. The tests would do one quadrant of the mirror surface at a time, using a CCD camera to record the results. They had two CCD systems from Photometrics, one a 512 x 512 element array and the other a 1024 x 1024 element array. This was an attempt at an innovative approach, since the Hartmann screen was also tipped relative to the mirror. Gary's recollection was that they got promising results but the development wasn't carried out to "fruition."



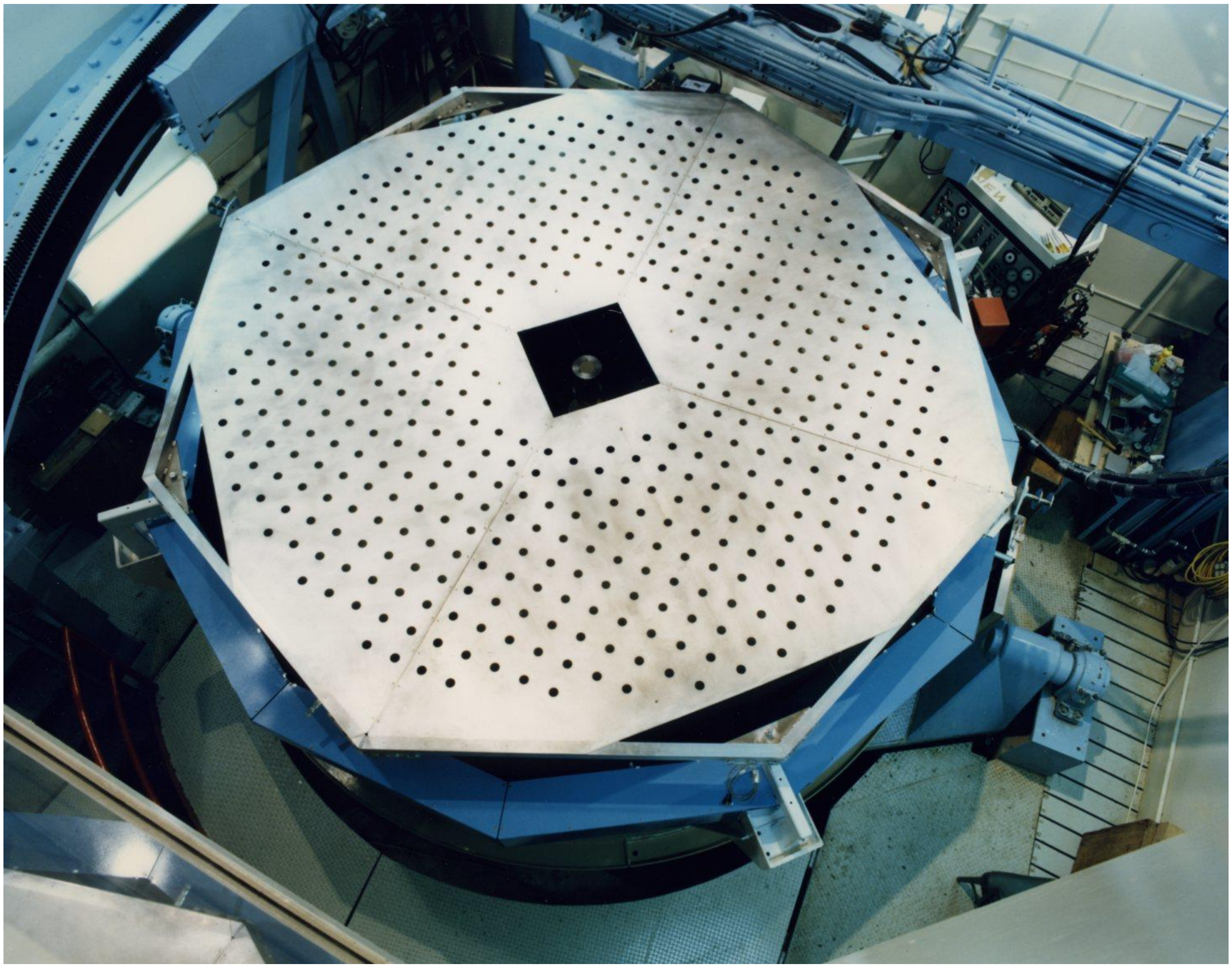
*Caption: Gary Polczulp looking across the mirror as the screen is lowered*

**(02:01:28)**
The Hartmann screen being positioned prior to testing. On the right one of the side panels is off showing the wires and instrumentation.



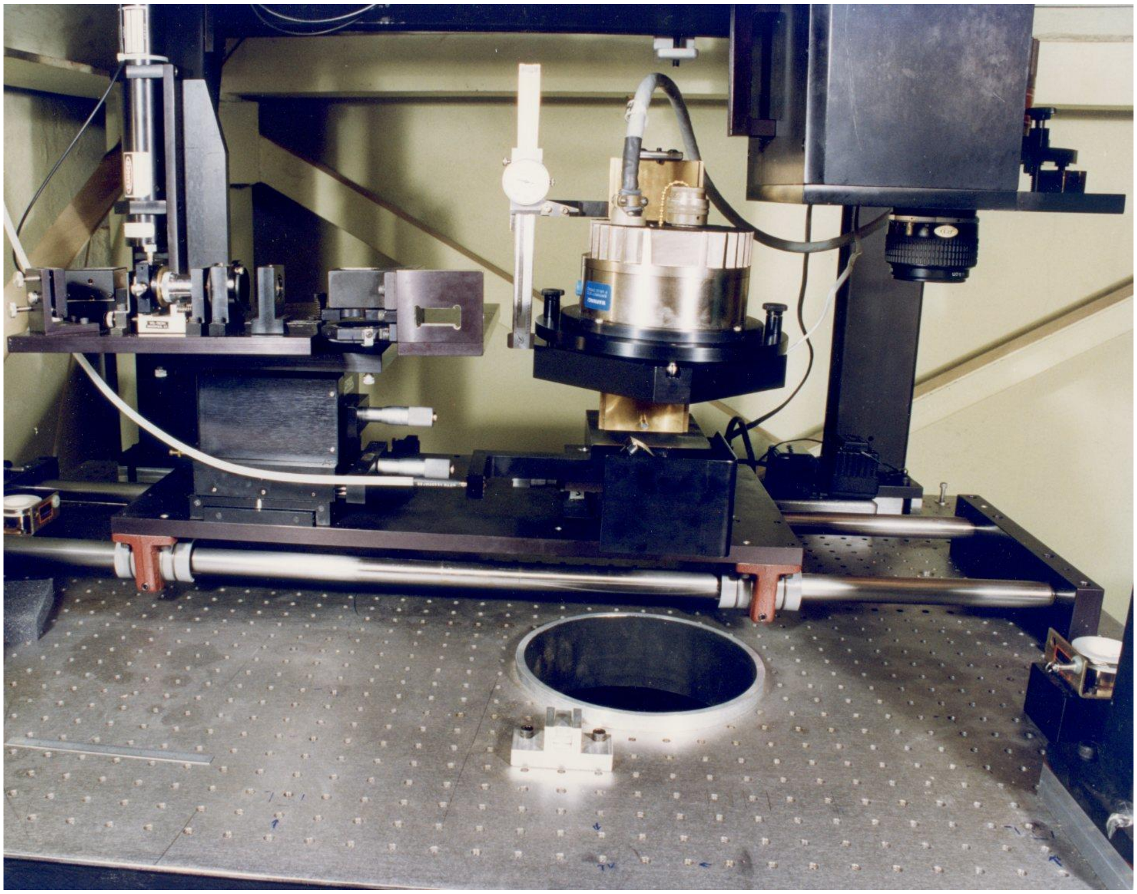
*Caption: The Hartmann screen is shown in place.*

**(02:02:23)**
The Hartmann screen is shown in place over the mirror, resting on the supports that define its position. On the right the panel suspended from the cell holds an array of manometers for measuring the air pressure at various locations in the cell. There is a clear cover over the side panel to maintain the air pressure. The manometer support was located close to the machine axis used to tip the cell for testing.



*Caption: Overhead view of the Hartmann screen in place*

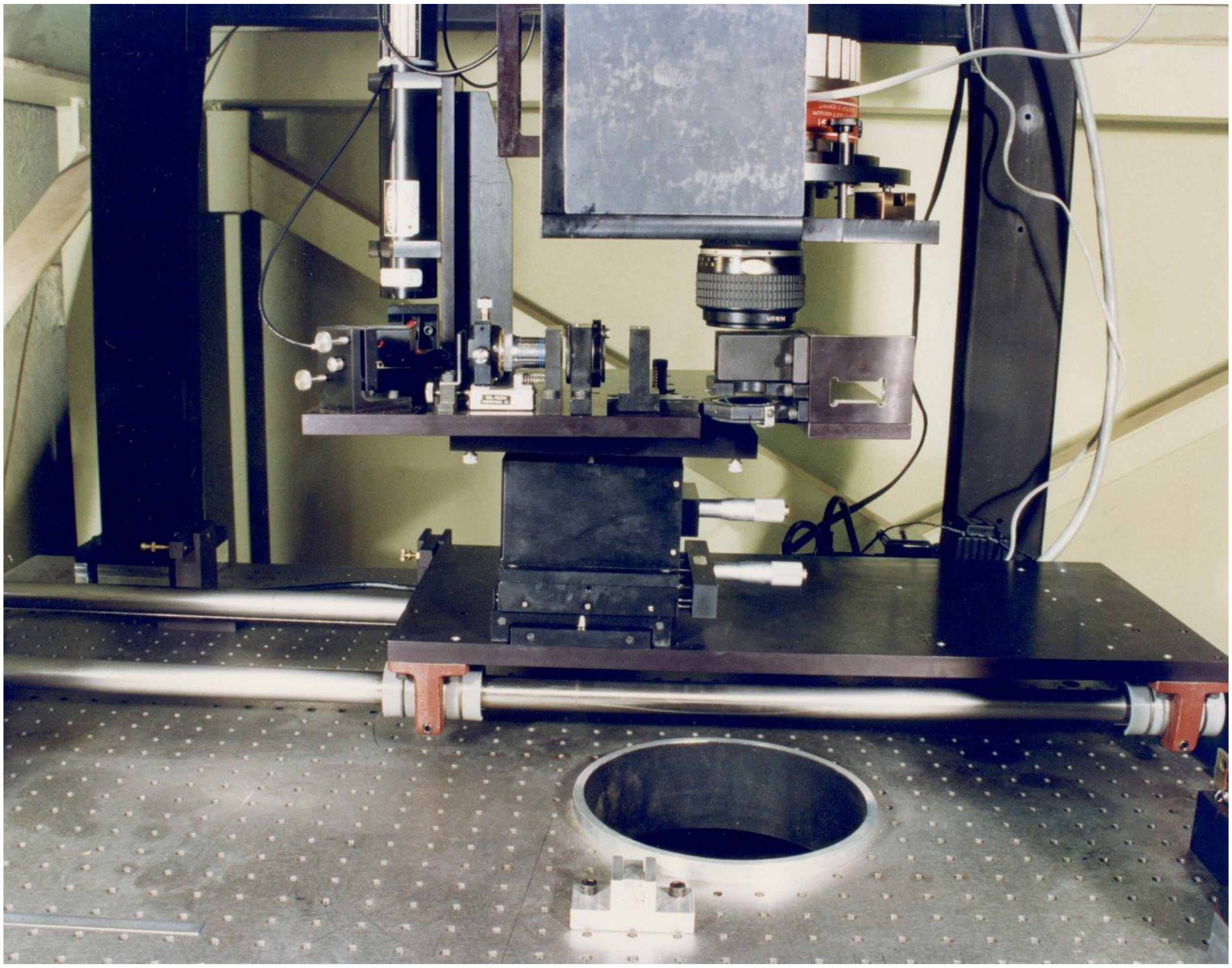
**(02:03:22)**



*Caption: Optical testing instrumentation*

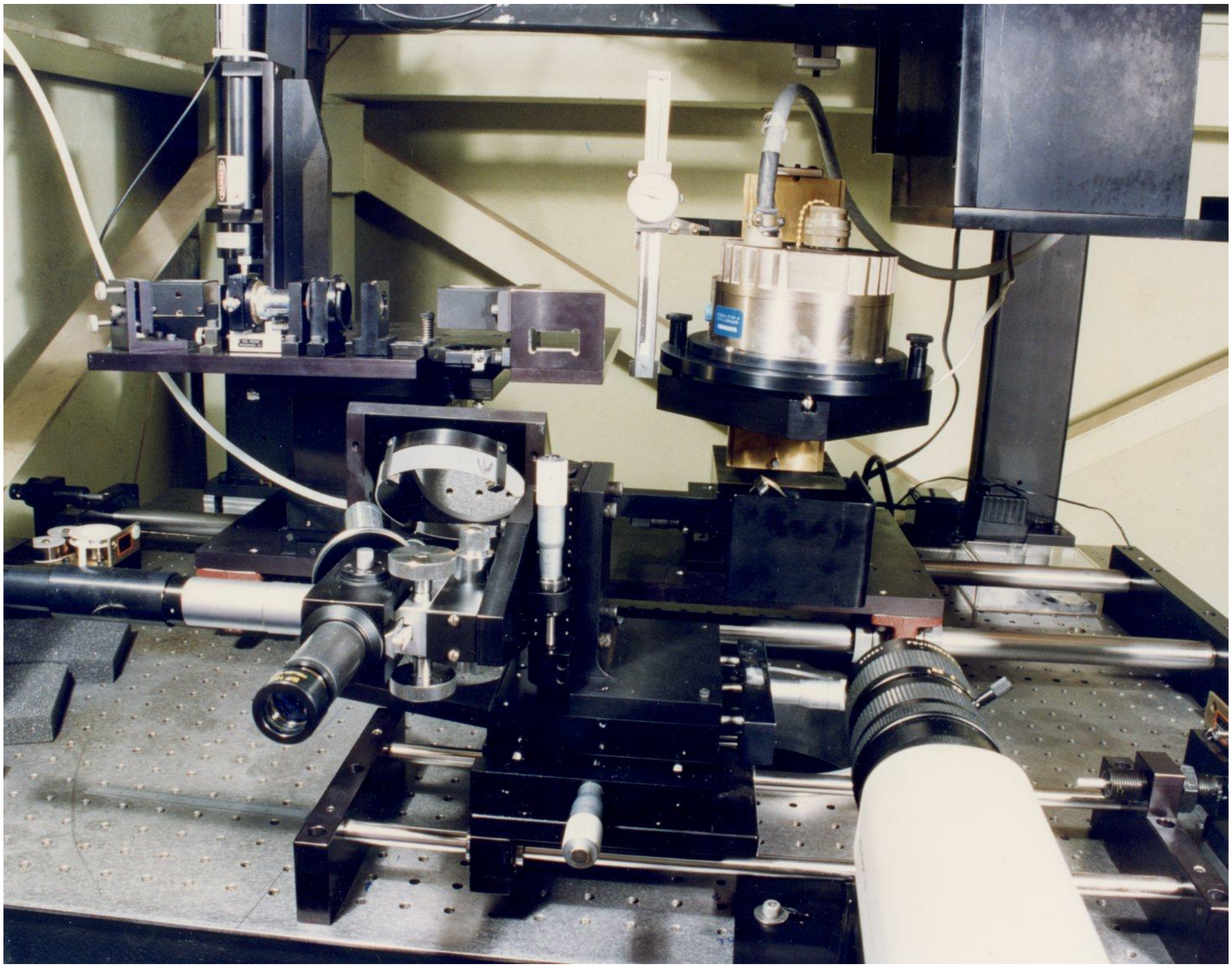
**(02:04:01)**
View of some of the optical testing instruments on an optical bench installed at the top of the test tower. What appears to be a wall are the cement counterweights for the tower. To access this area they had to go up above to the top of the tower then climb down to this area through a hatch in the floor. The optical table was suspended from above so that someone in this area wouldn't have to touch or shake the bench. This equipment was meant to be run remotely from a room containing the instrument electronic controls adjacent to the test tower (off of the area that later became the drafting area). That room basically became Gary's office while carrying out the tests.

At the upper right the black box with a lens pointing down was one of the CCD cameras. That was for the scatter plate interferometer which is on the left side of the image. These were all mounted on sliding rails to move them in and out of the beam going to/from the mirror. In designing this unit Bob Harris measured Gary's head to know how much room to leave so that Gary could stick his head into position, since this space was very tight.



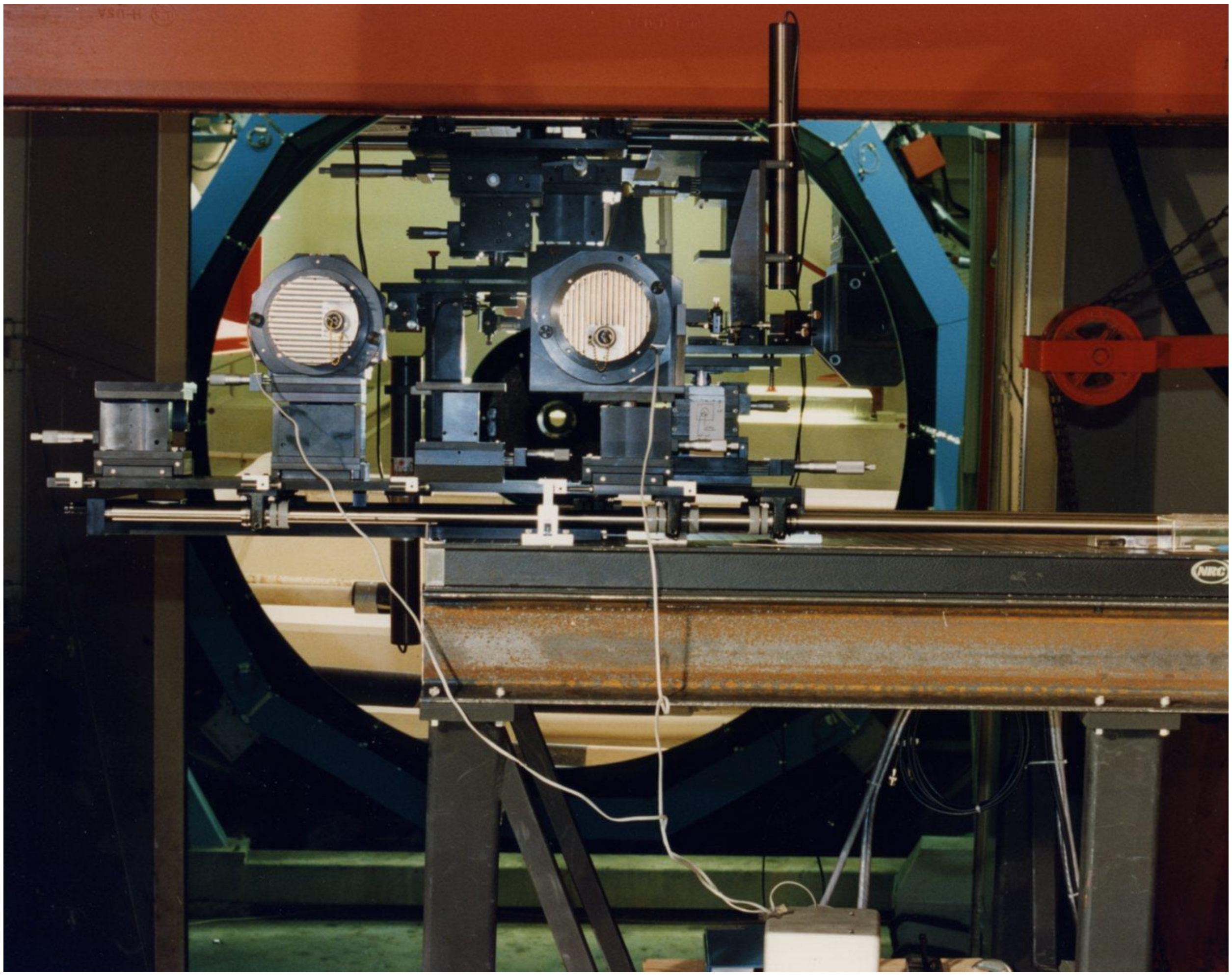
*Caption: The interferometer slid into place above the beam access hole in the bench.*

**(02:06:42)**
The interferometer moved into position over the beam access hole. The CCD camera is at the top, looking downward. The cameras were mounted on kinematic mounts so that they could be removed and relocated to the basement location for horizon pointing tests using a duplicate scatter-plate interferometer for the horizon pointing measurements.



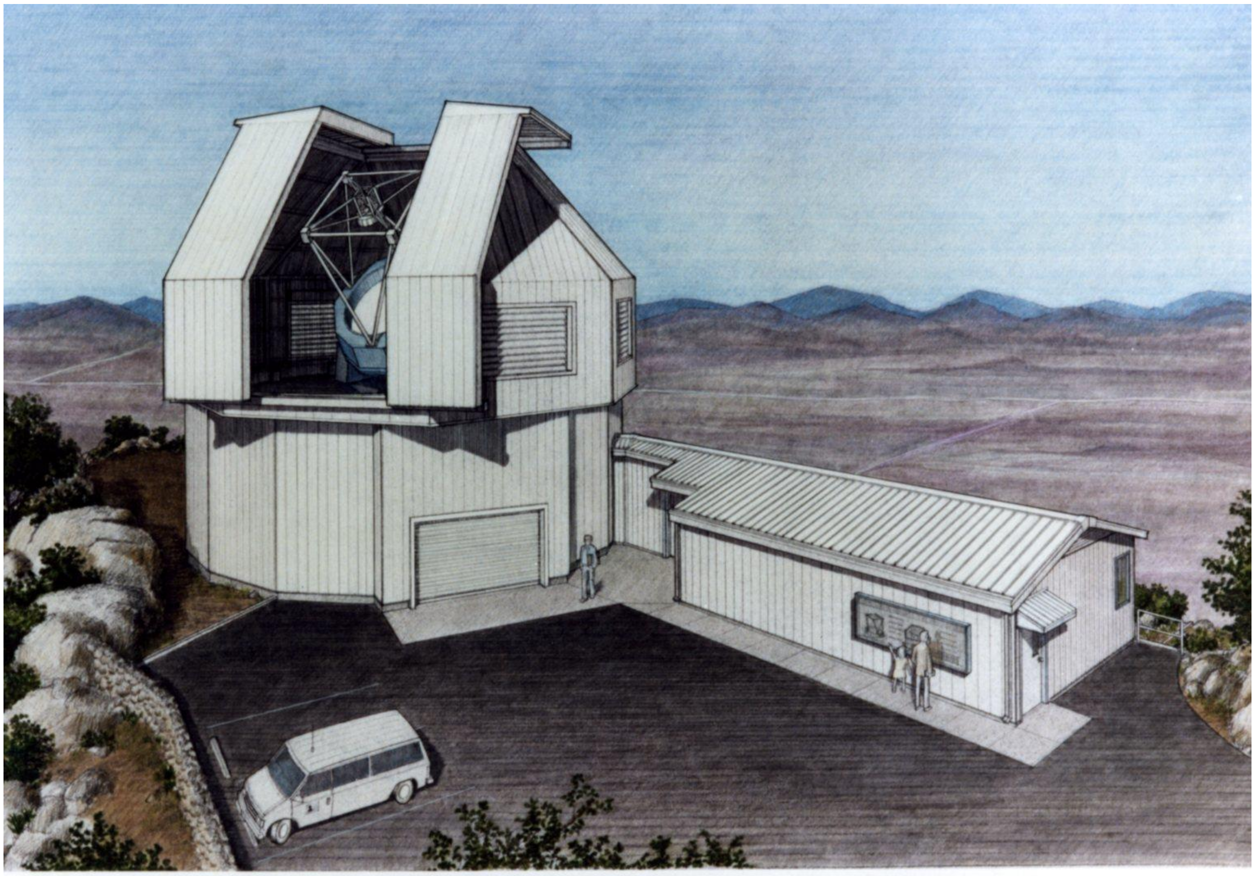
*Caption: TBD*

**(02:07:46)**
The interferometer has been slid out of the beam. There is an auxiliary platform in the front center with a Cohu TV Camera at the lower right. In the foreground there is another slide mechanism holding an eyepiece for viewing an artificial star image.



*Caption: TBD*

**(02:08:44)**
The image shows the two CCD cameras side by side looking towards the mirror 12.8 [12.5] meters away tipped up with its axis horizontal. The platform holding this setup is about 15 feet above floor level in the basement. The laser for the scatter-plate interferometer is in place. What appears to be equipment at the top is actually the inverted reflected image of the equipment on the support stand.



WIYN 3.5 meter Telescope

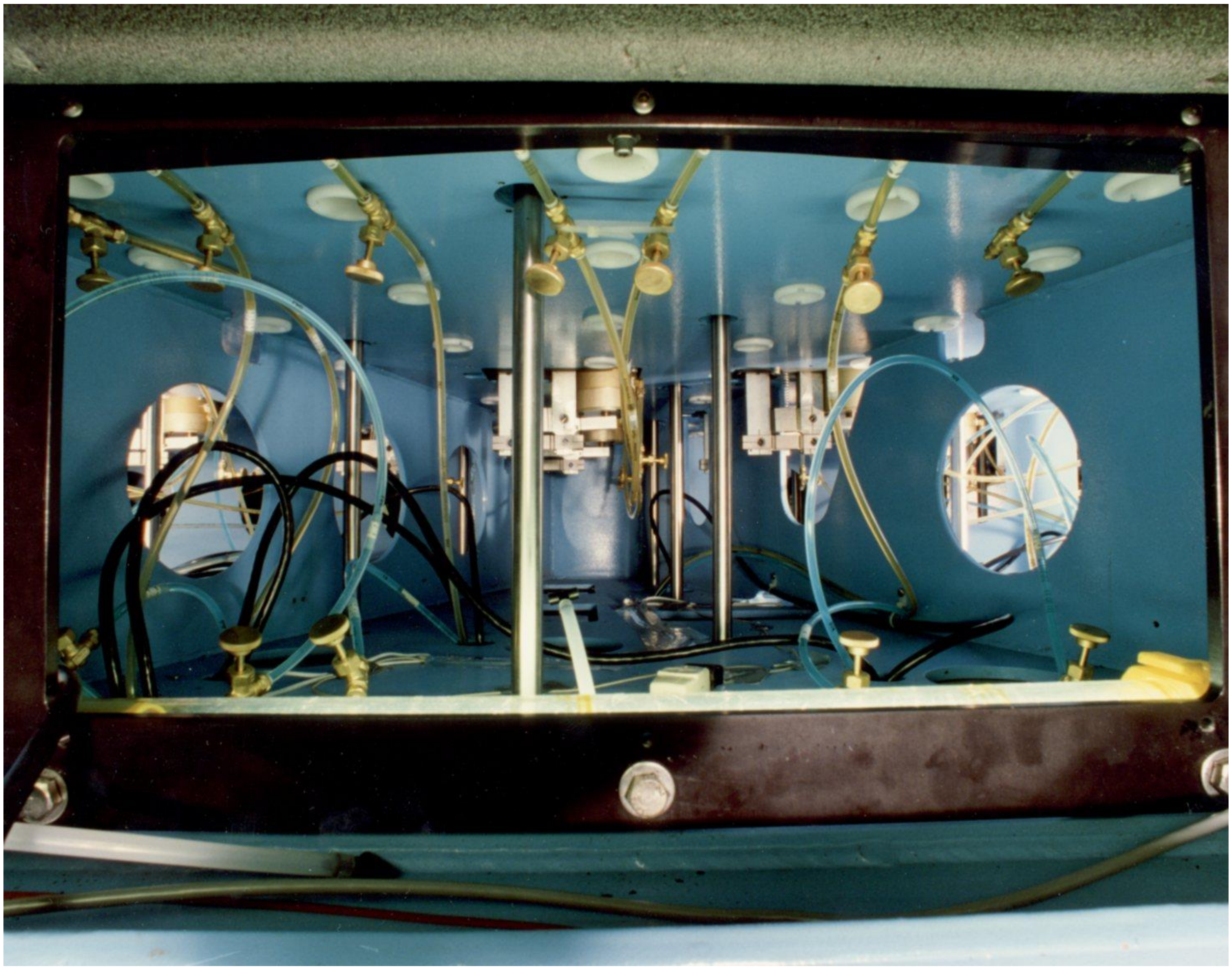
*Caption: Artist's rendering of what the completed WIYN facility would look like*

*Caption: TBD*

**(02:10:27)**
The groundbreaking ceremony for the WIYN facility which was on the site of the #1 36-inch telescope.

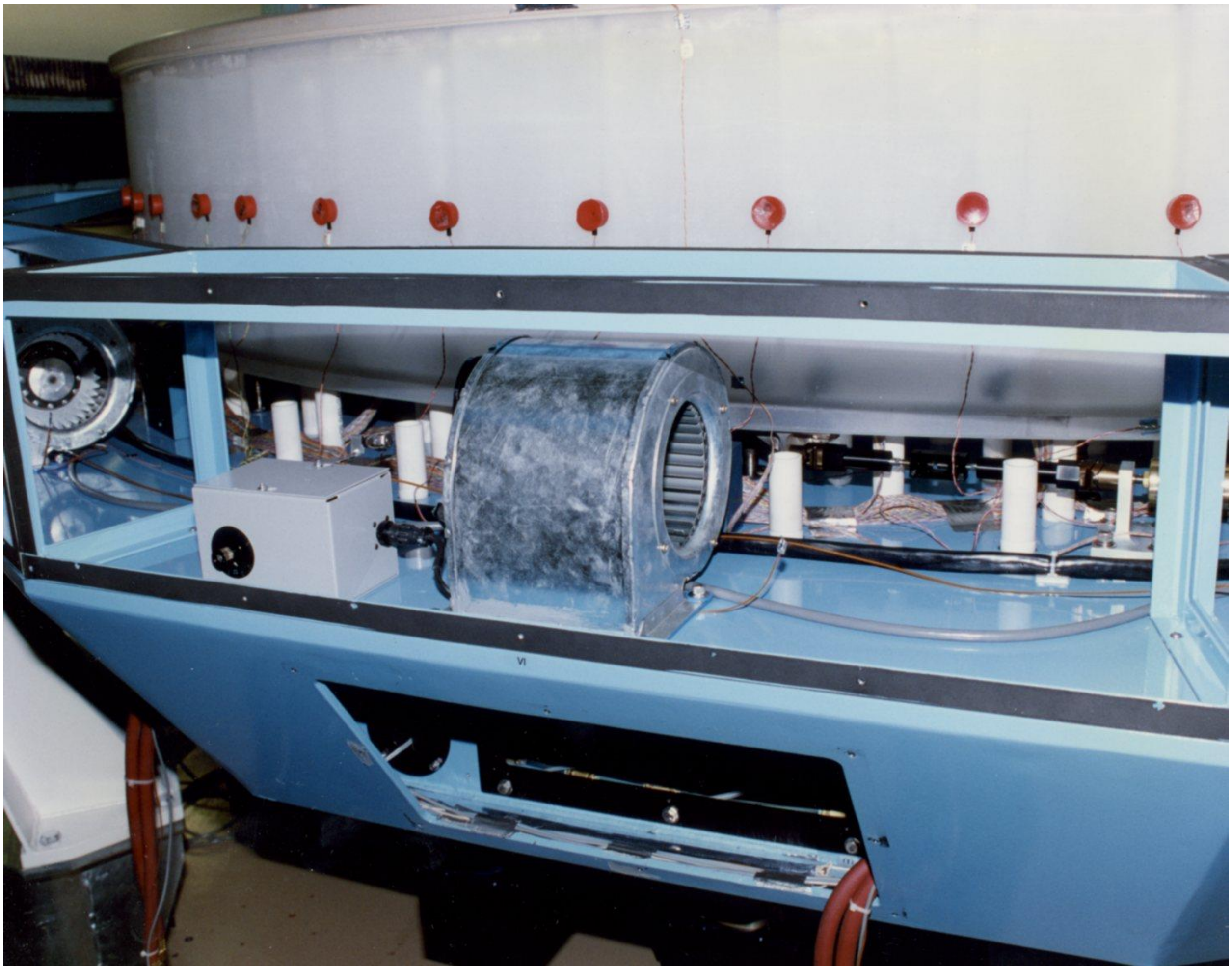
*Caption: TBD*

**(02:10:59)**
The "unofficial" groundbreaking by John Richardson, Max Brey(sp?) from Phoenix, and Gary Poczulp on the right (in his Indiana Jones hat)



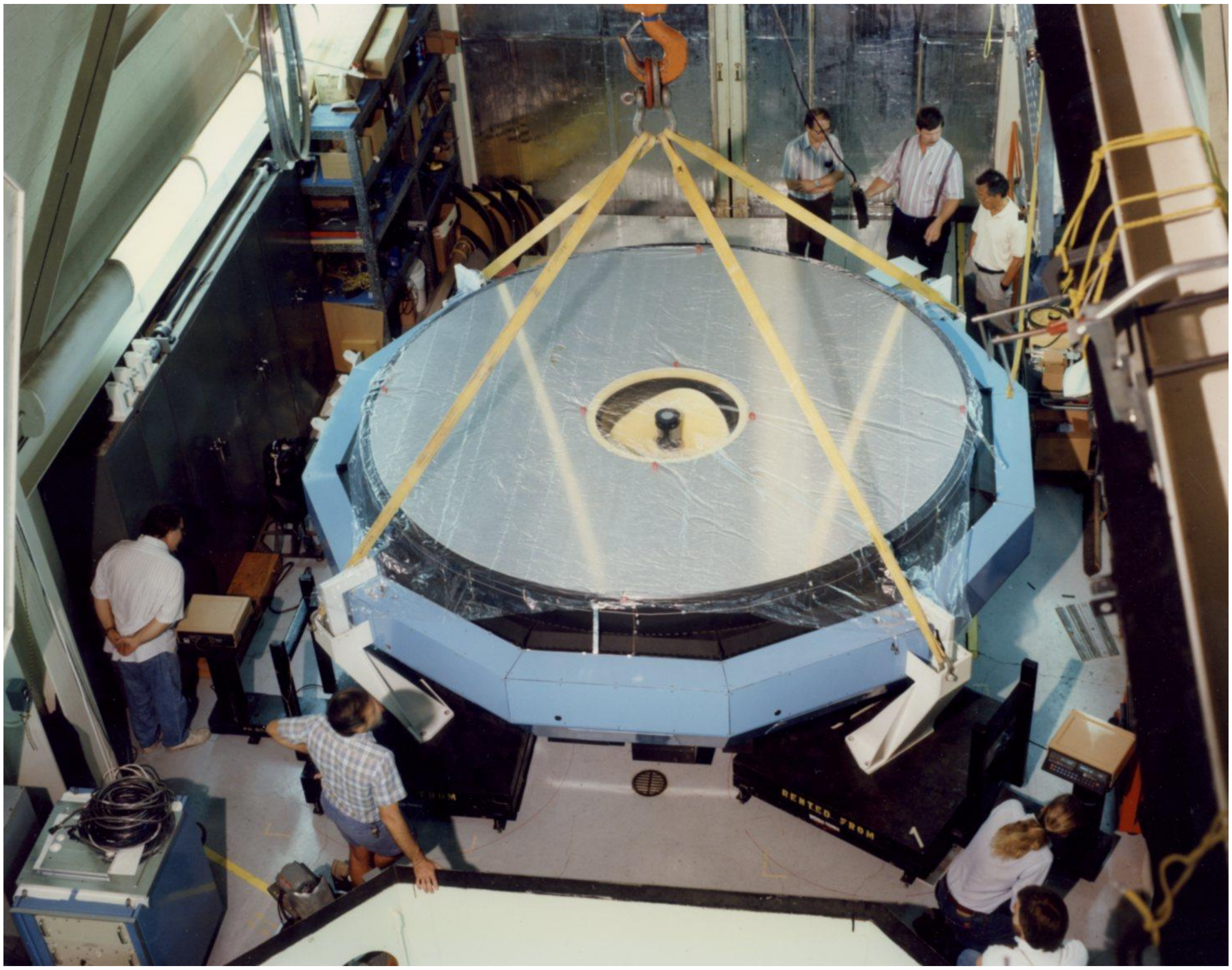
*Caption: TBD*

**(02:12:11)**
View looking inside one of the mirror cell side plates, showing some of the support rods that go from the first generation of mirror supports below to that back of the mirror above. The white circles at the top are the entrance nozzles for the thermal control air ventilation into the 296 cells. The tubing is part of the hydraulic control of the axial support system, with a number of valves for isolating different parts of the system. Most of that was done by Larry Goble, who did a lot of the mechanical engineering for the supports and the thermal control system.



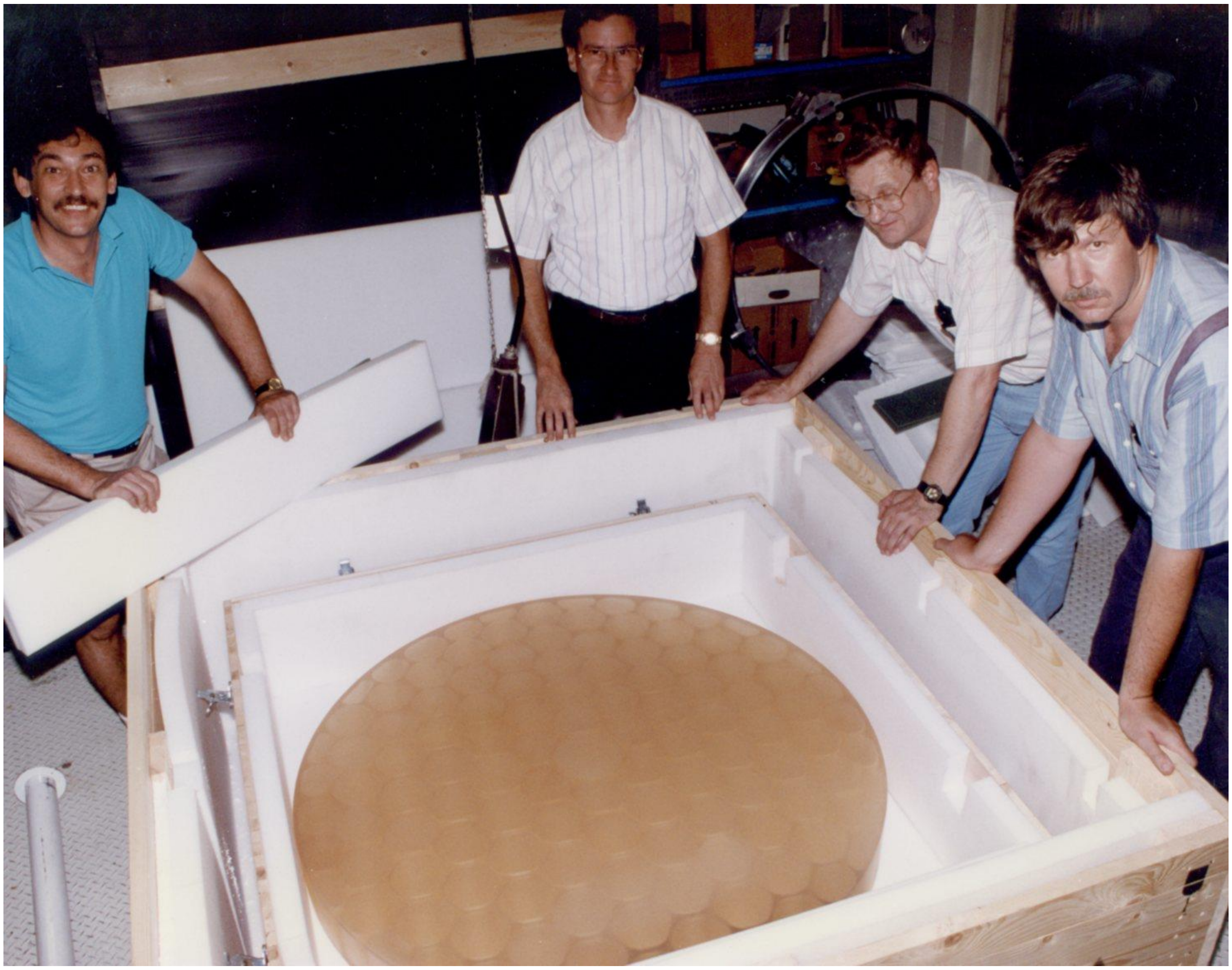
*Caption: TBD*

**(02:13:19)**
At the top is the edge of the mirror with the red-capped thermal sensors. At the center is one of the 12 squirrel cage blowers. The open hatch at the bottom goes into one of the heat exchangers, with the red hoses taking the fluid to the plumbed system. The white nozzles blow the temperature-controlled air up into the cells in the honeycombed mirror pockets.



*Caption: Top, left to right: Richard Wolff, Gary Poczulp, Woon-Yin (William) Wong; Bottom: right, Scott Benjamin; lower left, Dave Dryden (looking up); far left, John Kapp(?)*

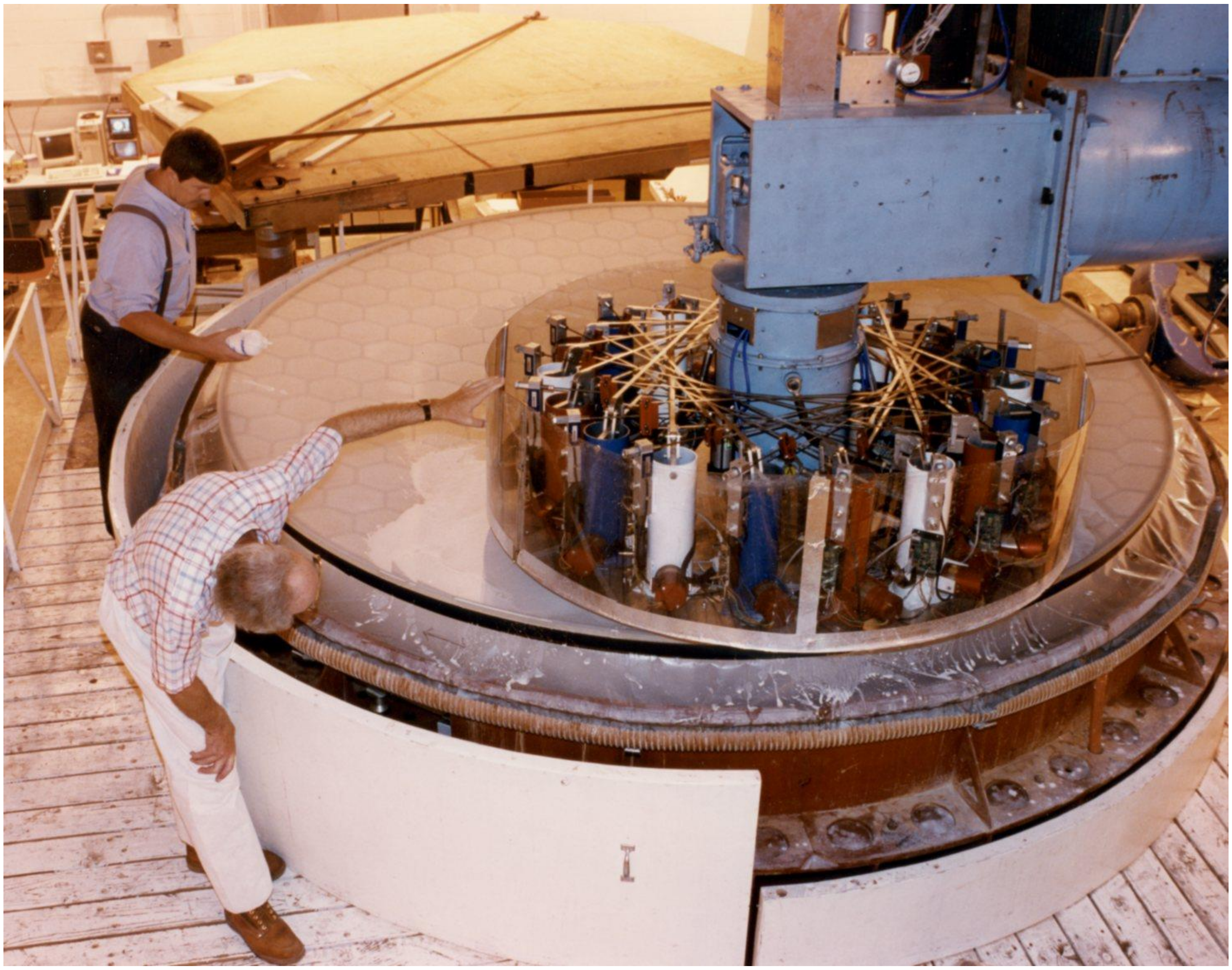
**(02:14:02)**
The mirror in its cell, which is suspended from the crane, being operated by Gary at the top right. The light plastic over the mirror protects the mirror from dirt or oil from the crane. They took four scales, one under each of the white support legs, to measure the total weight. This was in preparation for sending it to the Mirror Lab.



*Caption: Left to right: Dan Blanco, Matt Johns, Jerry Duffick(sp?), Gary Poczulp*

**(02:16:13)**
Inspecting the blank for the WIYN secondary mirror when it was received from Schott after its machining. It is a lightweight Zerodur material. This was the second one because they had a problem machining the first.

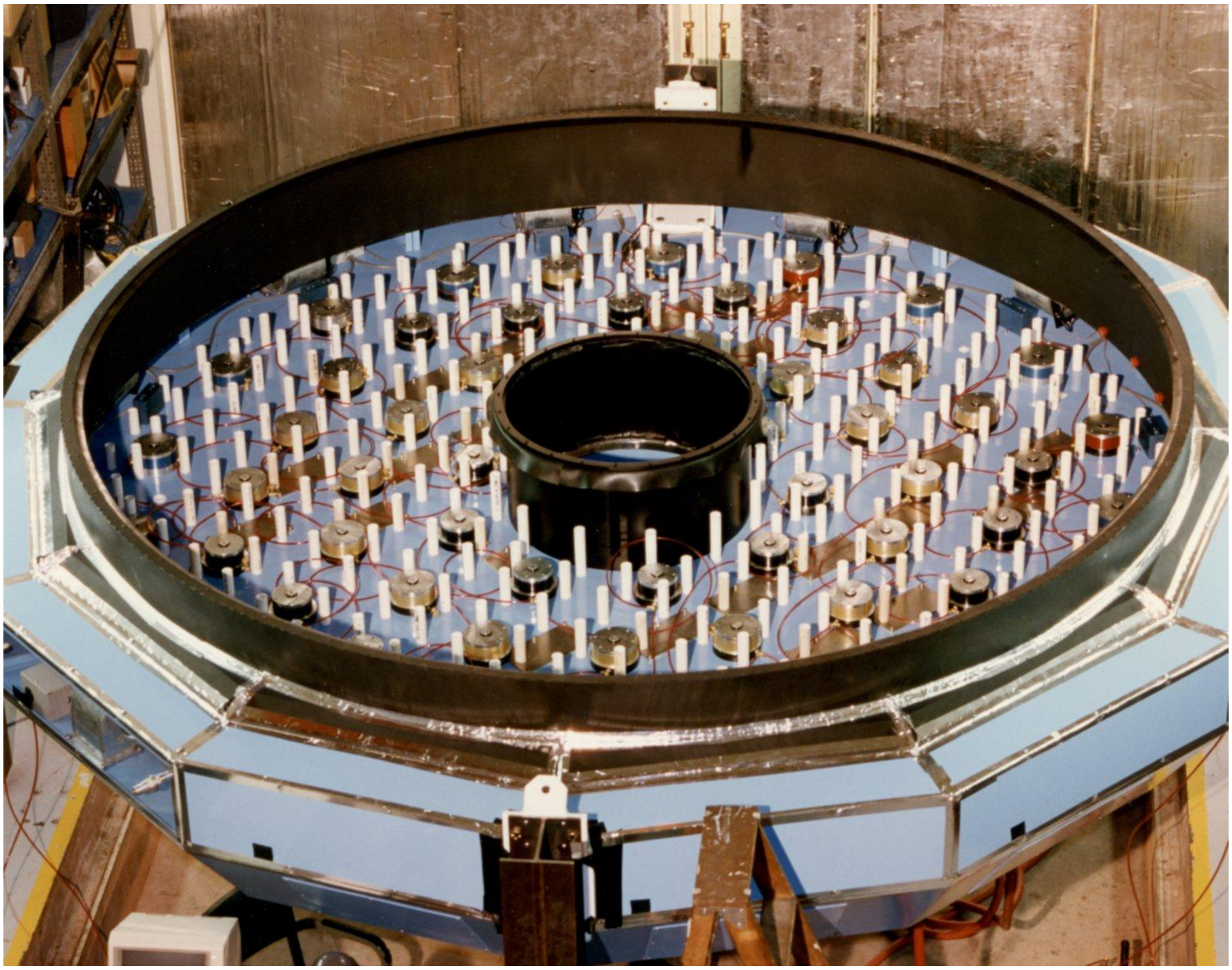
Gary took this blank up to the McMath-Pierce aluminizing area to acid etch (with proper safety precautions) the cores of the light weighting cells on the back side. He used a kiddie wading pool for the dilute HF acid, with a small peristolic pump to siphon the acid from one core to another and irrigate all of the core structure. The goal is to remove the subsurface damage and strengthen the material. Gary isn't sure that what they did was adequate, given the news from Keck that found they had to go back and re-machine and etch all of the support points for the primary mirror segments after finding fractures had appeared with time.



*Caption: Left to right: Gary Poczulp, John Richardson working on the mirror at the UA Mirror Lab*

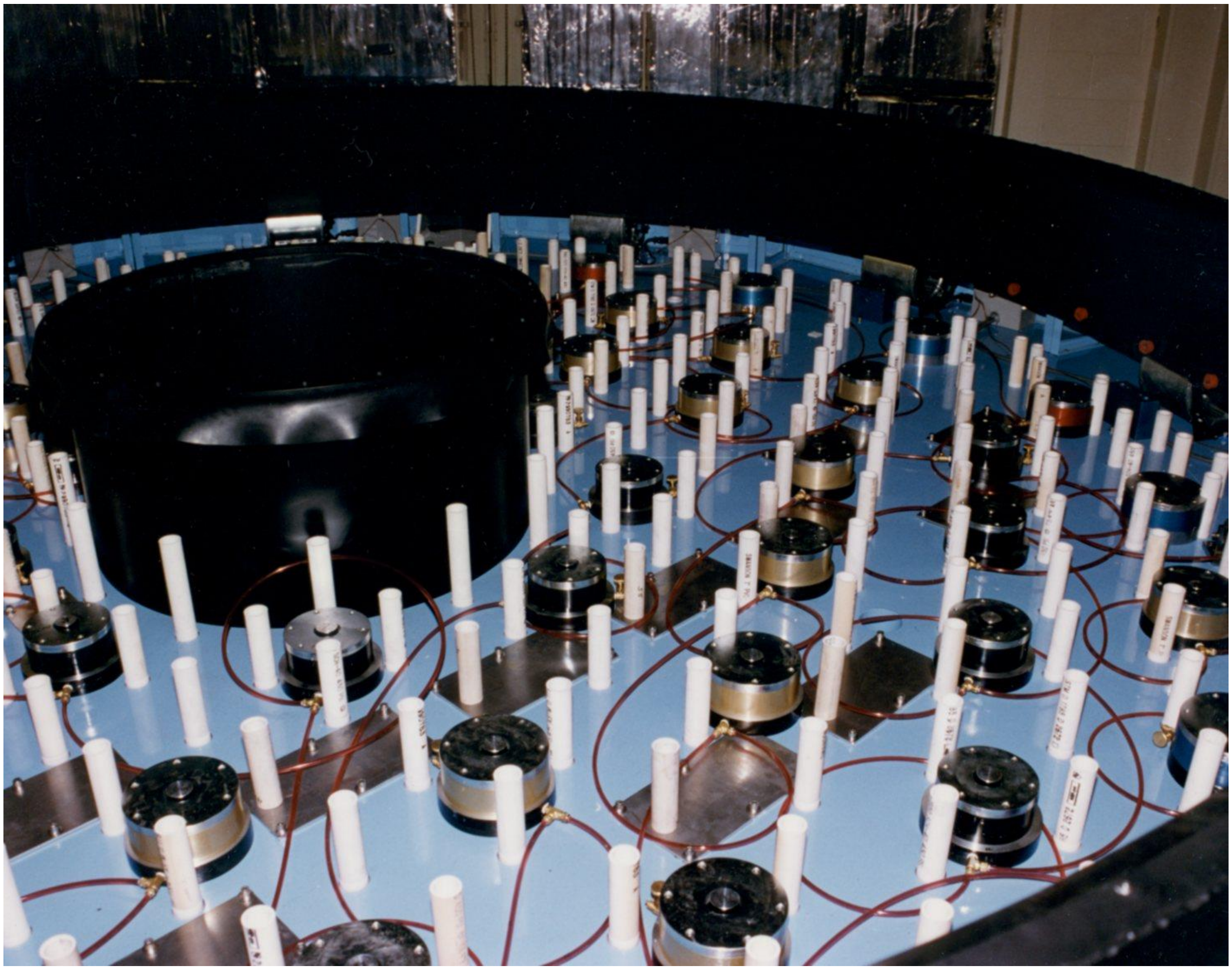
**(02:19:48)**
The WIYN primary mirror being worked on at the UA [Steward Observatory Mirror Lab] ~~Mirror Lab~~ using an early version of a stressed lap polishing tool. The bottom of the tool is an aluminum plate with grinding pads. This was the start of aspherizing the surface. The 66 active support actuators had been removed, and they used instead hydraulic belloframs in three zones to support the mirror like it ~~would be on the telescope~~ ([was on the 4m polishing machine). Gary had a bottle of aluminum oxide used for grinding the initial aspheric shape, since using polishing techniques only would take too long with a f/1.75 shape.

They worked for about nine months at the Mirror Lab with Dave Anderson and Dean Kettleson. Testing was done in the Mirror Lab test tower using a phase-shifting interferometer using a laser at 10.6 microns that gave interferometric accuracy on a ground surface. To approach the hyperbolic shape, they were deepening the center as well as removing some of the outer areas. For testing, the turntable assembly was on an air cart that they moved everything out under the test tower in the evening. They had to hook up the mirror thermal control system, let the mirror equilibrate, then take the test measurements. When they started the mirror still had its aluminum coating which they just ground off, since it is typically only 100 nanometers thick.



*Caption: TBD*

**(02:27:04)**
View of the cell as it was configured for polishing, showing the forest of air nozzles. The bands around the outside diameter and the center hole allowed them to seal off the mirror and use the air pressure to avoiding the quilting print-through effect from polishing pressures deforming the glass where it was not supported well between the ribbing. The hydraulic lines for the polishing supports can be seen weaving between the forest of nozzles.



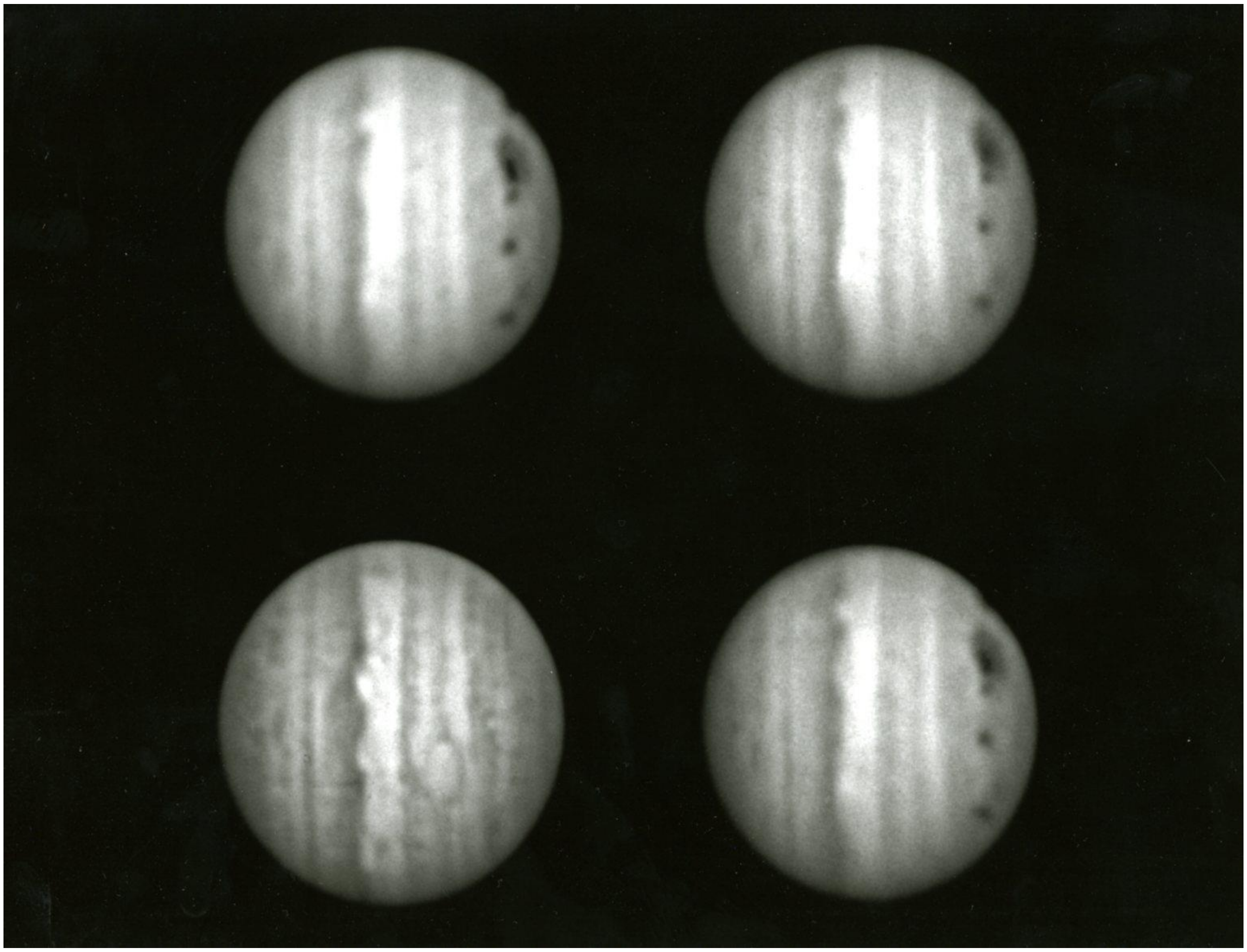
*Caption: Close-up view of the cell used for polishing*

*Caption: Completed WIYN facility*

**(02:27:50)**
Completed facility at Kitt Peak, looking very much like the artist’s rendition

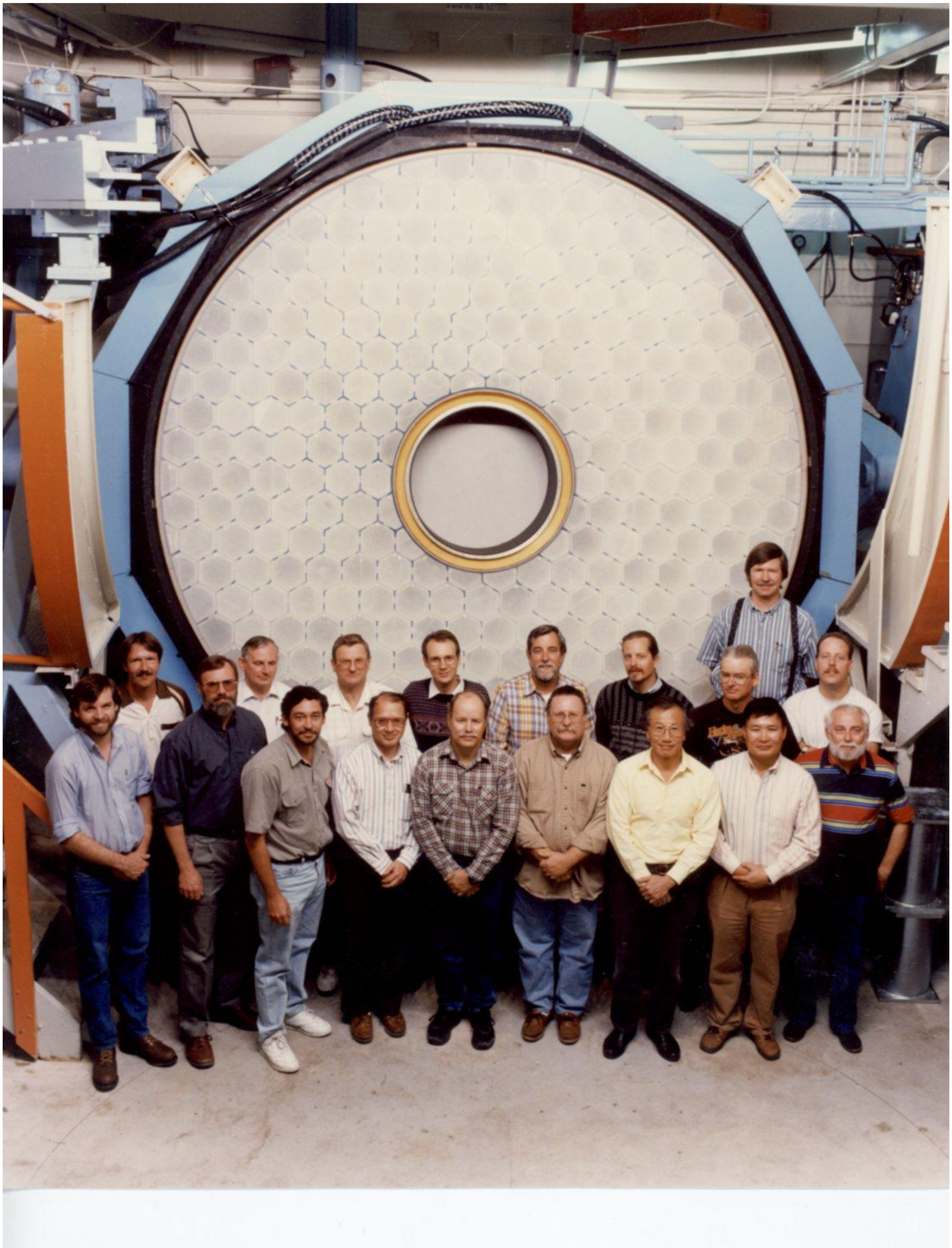
*Caption: Left to right: Dan Blanco, Dave Dryden (from Mountain Facilities), Nicolas Roddier, Gary Poczulp, John Kapp, Dave Sawyer, Ron Harris, Scott Benjamin*

**(02:28:14)**
The finished mirror being raised from ground level in the WIYN dome prior to its first installation in its cell at the telescope. Cell is in the background waiting for the mirror.



*Caption: TBD*

**(02:31:30)**
Jupiter as imaged with WIYN showing the impacts from Comet Shoemaker-Levy 9 in 1994



*Caption: Front row, left to right: Lee McComber, Larry Stepp, Dan Blanco, Richard Wolff, ?, John Kapp, Woon-Yin Wong, Myung Cho, Larry Junco. Second row, left to right: Roger Repp, Charles Harmer, Jerry Duffick, Nicolas Roddier, Dave Dryden, Scott Benjamin, Larry Goble, Ron Harris. Third row: Gary Poczulp*

**(02:31:58)**
Group picture of the many people involved with the WIYN primary mirror.

[Larry Goble and Scott Benjamin liked Harley motorcycles, as a result the dip stick for the hydraulic fluid is from a Harley motorcycle.]

The rib structure does not look symmetrical here because the camera was not centered right on the mirror optical axis. The glycol hoses for the thermal control system are at the top. This photo was taken prior to the mirror being taken over to the Mirror Lab.

*Caption: Left to right: Gary Poczulp, John Richardson, and Norm Cole*

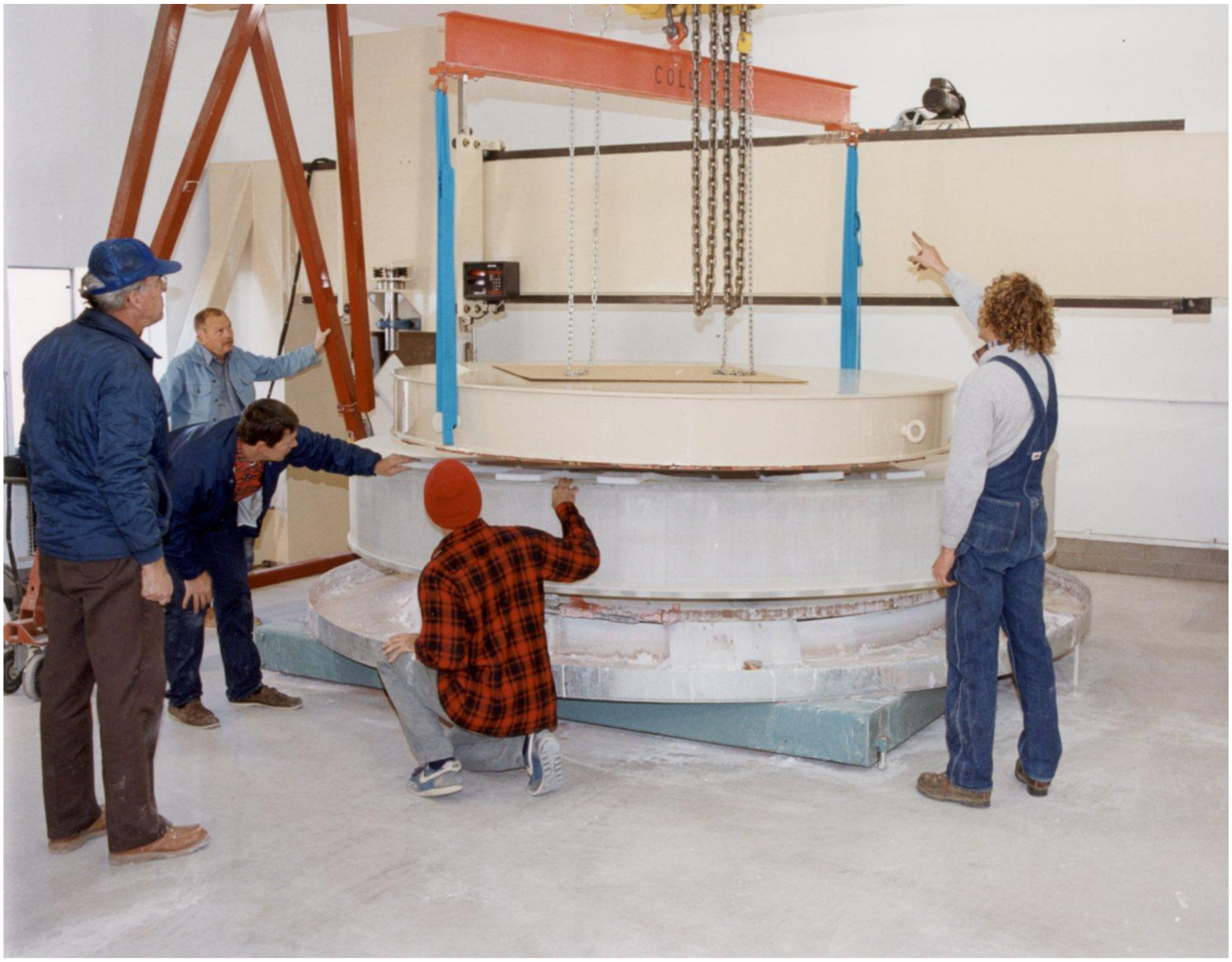
**(02:38:39)**
Gary and John Richardson went to visit Norm Cole at his optics shop at his home.

*Caption: ?, Norm Cole, Norm's son(?)*

**(02:39:37)**
The ARC mirror being worked on at Norm Cole's shop. He was using a very large tool.

The fellow in the overalls ended up working at the Mirror Lab, and when they had one of their machines installed in the NOAO Optics Shop, he'd come over to work on the mirrors for the deformable secondary mirror for AO.

*Caption: Grinding tool at Norm Cole's shop*



*Caption: At Norm Cole's shop*

## Abbreviations Used in Transcription

| *Abbreviation* | *Full Term* |
|---|---|
| SO | Steward Observatory, University of Arizona |
| KPNO | Kitt Peak National Observatory |
| IRTF | Infrared Telescope Facility [NASA] |
| CTIO | Cerro Tololo Inter-American Observatory |
| m | meter |
| NOAO | National Optical Astronomy Observatory |
| MMT | MMT Telescope |
| WIYN | Consortium consisting of the University of Wisconsin, Indiana University, NOIRLab, and the University of Missouri (previously Yale University was a member). Pre-FY19 and the creation of NOIRLab that included NOAO, the member was NOAO rather than NOIRLab. The consortium oversees two telescopes at KPNO: the WIYN 3.5m and the WIYN 0.9m. |
| SOML | Steward Observatory Mirror Lab |
| rpm | revolutions per minute |
| UA | University of Arizona |
| AO | adaptive optics |
| CCD | charge-coupled device |
| TBD | to be determined |
| Mirror Lab | Refers to what is (in 2020) the University of Arizona Richard F. Caris Mirror Lab, Steward Observatory, University of Arizona. It is also referred to as the Steward Observatory Mirror Lab. |
| sp? | Question regarding spelling |