# OPTICAL SCIENCES

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

TECHNICAL REPORT 3

# FABRICATION OF LARGE RZ GLASS DISCS

A. B. MEINEL

1965

# OPTICAL SCIENCES

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA


TECHNICAL REPORT 3

# FABRICATION OF LARGE RZ GLASS DISCS


A. B. MEINEL



1965

# THE

# EVALUATION OF ZERO COEFFICIENT RZ GLASS

# FOR

# LARGE DIAMETER OPTICAL SYSTEMS

A. B. MEINEL

OPTICAL SCIENCES CENTER
STEWARD OBSERVATORY
THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

COST: $759,175

David L. Patrick
Coordinator of Research

CONTENTS

# EVALUATION OF ZERO COEFFICIENT RZ GLASS

# FOR

# LARGE DIAMETER OPTICAL SYSTEMS

## I. SUMMARY

The problems connected with the utilization of large high-resolution telescopes are concentrated into two principal areas. The first concerns the physical properties of the mirror disc; the second involves the processing of the mirror in the optical shop.

This technical report concerns, 1) the design of a new type of optical polisher, one with a stationary mirror platform, and, 2) the casting of large discs made up of a new type of glass. This new glass, designated type RZ by Owens-Illinois, has a zero coefficient of thermal expansion at 25° Centigrade. A proposal for research in these two areas has already been made.

This research has been supported, in part, under Contract ONR-2173-(12) by the Advanced Research Projects Agency and administered by the Office of Naval Research.

## II. INTRODUCTION

The development of large size high resolution optical systems for space applications is dependent upon development and exploitation of much new optical technology. Up to the present time the technological requirements for optical performance have not exceeded current state-of-the-art in telescopes. This situation will not remain the case for operational requirements that lie in the immediate future.

To take a parallel case in the area of astronomical telescopes, it is well known that a system having an aperture around 40 inches diameter yields a higher angular resolution for detail than does a larger telescope. It is in fact possible to build and use telescopes in the 30-40 inch size that perform very close to diffraction limit under ideal laboratory conditions, and that yield resolutions of the order of one-third of a second of arc in operational use. The prognosis for building larger systems that maintain the same relative performance in terms of the diffraction image size is somewhat uncertain. One area of particular concern in this regard is the fabrication and figuring of the large diameter primary mirror of such a system.

New materials such as the ceramic glasses Pyroceram and CerVit, the zero-coefficient fused silica, and now the new zero-coefficient glass designated type RZ by Owens-Illinois are attractive new materials of intrinsic importance for space optics. In a recent review of the general situation that I have made for SAF-SP, it would appear that the exploration of the potentiality with regard to both CerVit and Pyroceram is well in hand. The application of zero-coefficient fused silica appears to be limited to the familiar egg-crate construction because of the high melting point and viscosity of silica. The RZ glass does appear to be a new material with a wide potential range of fabrication possibilities.

In view of the rather different and promising properties of the zero-coefficient RZ glass recently developed by Owens-Illinois, we would propose to explore its applicability for optical uses by casting a number of experimental mirror discs. The program would include the casting of a mirror in the 80-100 inch diameter class following the procedures outlined in this proposal.

The mirror would be cast by Owens-Illinois and polished and figured by the Optical Sciences Center and evaluated in the new University of Arizona telescope. Several mirrors of intermediate size would be cast and polished as part of the evaluation and development of the techniques necessary for the larger size. In order to avoid problems associated with taking too large a technological step at one time, we would propose to cast light-weight mirrors in which the weight factor is approximately 40 percent. This would appear to both us and Owens-Illinois as a reasonable single step toward the very light-weight cast mirrors in the 15-25 percent range that would be important in space telescopes.

## III. PROBLEMS OF LARGE MIRRORS

A. <u>Internal thermal gradients</u>.

The optical performance of large mirrors is affected by a number of causes. One of the major causes of image quality degradation is internal thermal gradients in the mirror. These gradients are the result of a changing thermal environment. In the case of an astronomical telescope the environmental characteristic period is 24 hours and in the case of a space telescope it is the order of 90 to 120 minutes. In both cases the rate of change of temperature is approximately the same, the principal difference being that a terrestrial telescope has several hours in which to stabilize both during the night and during the day. Since both types of telescopes must operate in a changing environment, the only solution to this source of optical degradation is to use a mirror material that has a zero-coefficient of thermal expansion.

Most astronomical telescopes have been made with Pyrex mirrors in which the coefficient of expansion is approximately 24 to 32 x $10^{-7}/°C$. Only recently has fused silica become available in the large sizes necessary for astronomical instruments. Fused silica represented a very major improvement relative to Pyrex in regard to thermal deformation of the mirror. Fused silica, however, still has too large an expansion coefficient to permit the attainment of diffraction-limited performance in the presence of a changing thermal environment, especially in the use of light-weight optics. For this reason much recent attention has been given to the development and utilization of materials with still lower coefficients of expansion, such as Pyroceram and CerVit. These ceramic-glass materials have properties that permit the attainment of coefficients that can be made very close to zero. Typical values for these materials are in the range from +1.0 to -1.0 x $10^{-7}/°C$.

The ceramic glasses have presented numerous problems in the fabrication of light-weight mirrors because of certain properties inherent to these materials. The availability of the RZ glass, a true glass of zero-coefficient of expansion, now offers a material with different handling properties for the fabrication of light-weight structures that should be immediately explored, and which offers the opportunity to construct large diameter mirrors that are quite insensitive to thermal gradients and thermal changes.

B. Optical processing figure errors.

The second major cause of image quality degradation in a large astronomical mirror is irregularities and warps of the optical surface. These errors represent residual zones left in the mirror at the end of optical polishing. Additional warping of the mirror can arise from mounting stresses. An example of this problem is shown in Fig. 1, which represents the surface error contour map for the 84-inch Kitt Peak mirror as determined by a Hartmann diaphram test. A description of the Hartmann tests is given in Section III, "Introduction to the Design of Astronomical Telescopes" by A. B. Meinel. A pre-print copy is attached to this proposal.

The contour map shown in Fig. 1 indicates that the optician has done a good job by current standards, in that there are no radially symmetric zones remaining from the original optical figuring of this mirror. The cause of the deformation in this diagram is attributed to random warp of the mirror both remaining from optical processing and resulting from mounting deformations. Up to the present time no one has applied the precision of this type of test and evaluation of the mirror to the mirror while it is still in the optical shop. Considerable effort is currently being applied to the introduction of interferometric testing methods, but these usually involve considerable effort to reduce and interpret. To date we have not seen the actual use of error contour maps in the optical shop.

In the case of the above tests of the 84-inch Kitt Peak mirror, a series of tests was made involving the addition of known forces to various parts of the mirror. It has been concluded that a significant fraction of this residual mirror figure was inherited from working in the optical shop. The origin of errors of this type therefore may be simply due to improper mounting of the mirror while it was being processed in the optical shop. One must remember that a large astronomical mirror must be treated, even in its early stages of grinding and polishing, with exactly the same care that one would exert during the later stages of polishing. One can inherit

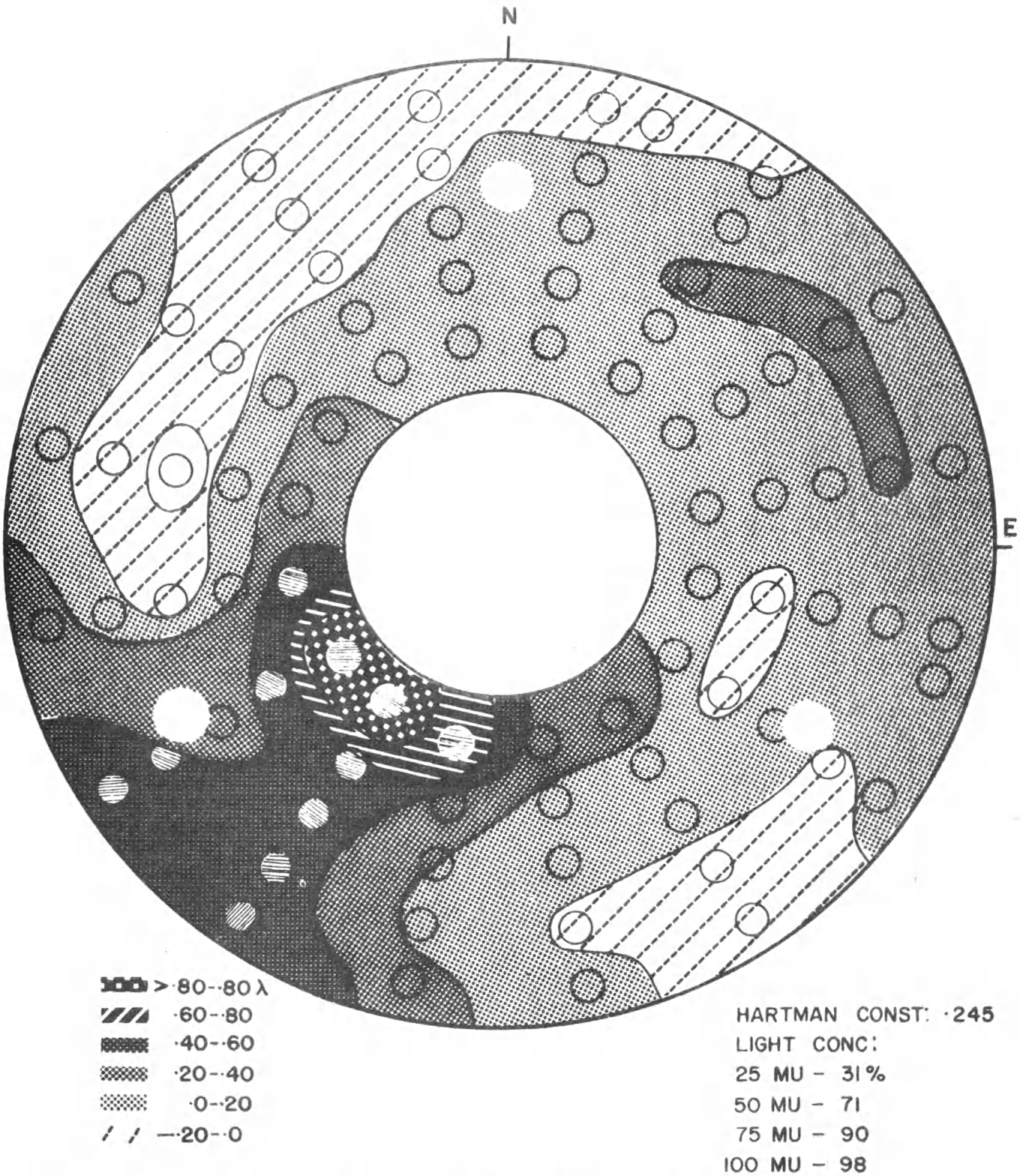



Figure 1. Hartmann contour map of the 84-inch Kitt Peak mirror during early tests of the mirror support system. The location of the holes in the Hartmann screen is shown by the small circles. The three large circles locate the collimation pads.

astigmatism and warp from improper mounting even in its early stages, even though the error will not show up until the mirror is nearly finished.

The problem of processing errors does not cause much trouble with smaller mirrors for the reason that a smaller mirror is relatively much stiffer than a larger mirror of the same geometrical configuration. This fact results since the stiffness of a mirror scales up at least as the square of the diameter. In other words, the 200-inch Palomar mirror has the stiffness equivalent to a 60-inch mirror of less than 1 inch thickness.

C. Mirror testing.

It is proposed that in our studies with the large mirrors of RZ glass, that contour image evaluation be made continually during the optical processing in the laboratory so that we can identify potential sources of the difficulty that may be of guidance to later design and manufacturing of large diameter precision optics.

Relevent to the problem of the final evaluation of large mirrors with the accuracy required for the diffraction-limited performance, we feel that there is no problem in carrying this out in an astronomical telescope. While atmospheric seeing disturbances normally limit the resolution of astronomical telescopes to a few tenths of seconds of arc under the best conditions, and a second or two of arc under average conditions, it is possible to obtain tests of the mirror that completely average out the effect of the atmospheric seeing. The procedure that has been used, starting with the tests of the 200-inch Palomar telescope mirror by Ira S. Bowen, is to make the tests of the mirror using a rather faint star. The required exposure time to obtain either the Hartmann test plates or Foucault knife-edge focogram of the mirror is long compared to the characteristic time of the seeing disturbance period.

It has been found that exposure times between one and three minutes are sufficient to average out the atmospheric seeing so that one can get a test that is significant to the order of a twentieth of a wave length. A twentiety of a wave length is about one quarter of the contour interval used in Figure 1.

The only factor that is present in the case of testing an astronomical mirror in the manner described above, but which is not present for a space telescope, is the force of gravity. In this regard we now, however, have means of supporting astronomical mirrors such that the forces due to stiction and mechanical hysteresis in the supporting mechanical structure, or in the air pad support, is less than one tenth of a per cent. Recent experiments have shown us that forces of this magnitude on a mirror with the stiffness of the 84-inch Kitt Peak mirror produce a negligible addition to the distortion of the optical surface.

D. Light-weight mirror optical shop technology.

The optical sciences group at the University of Arizona has recently begun a study of the fabrication problems presented by large light-weight mirrors. We feel that one of the basic limitations to the attainment of high precision light-weight mirrors can be attributed to the type of optical machine that is currently used in the optical industry.

The conventional optical polishing machine consists of a table in which the mirror to be polished is mounted. This table is rotated continuously during the polishing operation. The polishing is accomplished by a pitch-covered tool that is pushed back and forth by a stroke arm linkage as the mirror slowly revolves. While this polishing machine is basically a very simple type of machine we feel that it has distinct limitations when it comes to the requirements for the production of high precision light-weight mirrors.

In a conventional polishing machine it is very difficult to devise ways in which to monitor the mirror while it is being processed, due to the fact that there is a rotating interface involved. In principle, one would wish to instrument a high-precision mirror during optical figuring operations. One might even wish to apply pressure or shear forces to portions of the mirror during polishing to cause certain desired results in the polished surface figure. If one were to design a polishing machine right from the start that is specifically orientated to the problems of light-weight mirrors, we feel that one would elect to have the mirror stationary so that the necessary monitoring and other active operations could be performed on the mirror during the polishing observation.

## IV. TECHNICAL DISCUSSION

### A. The Stationary Table Optical Polisher.

Part A of this proposal involves the construction of a new type of optical polisher using the above concept of a stationary mirror machine. We feel that an optical machine of this type can generate new information that could significantly change and improve the boundary conditions that now determine the basic elements of a light-weight mirror structure design. A preliminary report on this type of optical polishing machine, that we term the Stationary Table Optical Polisher, is attached as Appendix A.

The Stationary Table Optical Polisher is built about a basic ring-girder track that has a large central hole to receive the mirror and its support cell. A creeper unit that moves around the periphery of the structure on the ring girder track carries the polishing arm. Various types of stroke arms can then be attached to the creeper, two variations of which are illustrated in the attached report. It is also possible to use more than a single creeper unit if one wishes to elect a stroke arm that completely straddles the mirror, as in the case of the Draper or Pittman style of polishing arm.

We would propose to construct a polishing machine of sufficient size to accommodate a 100" mirror following the design shown in Figure 2. We feel that this new type of machine could make a notable advance in the state of the art of optical figuring large mirrors and that we feel would be capable of exploratory work on light-weight mirrors in a unique way.

B. The RZ glass discs.

Part B of this proposal includes the casting of a number of solid and light-weight discs of the zero-coefficient RZ glass. We propose an orderly growth of disc capability with technical steps that are sufficiently conservative to avoid problems that often accompany a large extrapolation of the state-of-the-art. The end-product of this proposal, part B, would be the best-effort production of a 100-inch ribbed disc. The details of this program are covered in section VI.

This proposal consists of two parts. Part A is concerned with basic problems of polishing light-weight mirrors. A new approach to polishing machines is proposed in the expectation that it will permit an advance in the structural design of light-weight mirrors.

Part B is the casting of a number of discs of a new zero-coefficient glass in relatively conservative discs. These discs to be evaluated by conventional polishing as well as with the new polisher, when it becomes operational.

We propose that the USAF support this work in the following specific areas:

(1) a design and construction of two Stationary Table Optical Polishers, one of approximately 48" diameter and (2) one of approximately 100" in diameter. The smaller machine would have a shorter delivery schedule and could be assembled and evaluated significantly ahead of the 100" table.

(2) a casting of a number of experimental light-weight discs of light weight RZ glass by the Owens Illinois Company. We would propose a number of castings, initially solid, of approximately 30" diameter and 6" thick. We would then request the assignment by the USAF of one of its large furnaces for the melting of larger batches of RZ glass. The next stage would be the casting of several ribbed discs having only a continuous front plate. The first unbacked ribbed casting would be of approximately 30 to 40" in diameter.

The annealing of these blanks could be carried out with the existant facilities, subject to their availability for this work.

(3) the construction of a melting and anneal furnace for the 100" mirror. This furnace would be of a type very similar to that used by the Corning Glass Works for the construction of the Kitt Peak 84" pyrex mirror. A furnace of this type is a relatively simple device in which the RZ glass blank is remelted to flow into the mold and then annealed down to room temperature.

(4) the procurement of auxiliary small equipment required to do the evaluation of the RZ glass material and in support of the polishing of the RZ glass blanks.

The cost of Part A is $ 254,175 , to be expended over 2 years.

The cost of Part B is $ 505,000 , to be expended over 2 years.

The budget analysis is presented in Section VI .

# V. PROGRAM RELEVANCE

## A. Status of the U of A Optical Sciences center.

At the present time we have a proposal before the United States Air Force and the Department of Defense for a grant in support of the construction of laboratory facilities required by the optical sciences center program at the University of Arizona. This laboratory building will be provided with an optical technology shop that is particularly designed to be used for the exploration of the problems of very large high-precision optics. The optical shop consists of a large room with overhead handling cranes, plus two optical tests paths. The principle optical test path is a vertical shaft located over the position of the main optical machine. This tunnel is seven stories in height, running upward through the center of the building. The location of the test tunnel completely inside the building is to make the surrounding environment for the test tunnel as uniform as possible without active control. In Arizona the combination of heating during the winter and refrigeration air-conditioning during the summer results in environment of high degree of temperature uniformity throughout the year. We therefore expect that this vertical tunnel will provide rather excellent optical testing conditions, even though the optical path is not evacuated.

The experience at the Kitt Peak National Observatory Optical Shop is that a vacuum test tunnel is very inconvenient to use and that every effort should be made to obtain relevant optical tests without resorting to a vacuum system. We feel that time exposures, as in the case of actual testing with a telescope, will result in tests that are significant to the degree of accuracy required to identify problems.

The second test tunnel path, also with a 25 ft. cross-section, is horizontal and runs underground outside the periphery of the building.

Since the floor level of the optical shop is approximately 45 ft. below ground level, the external environment for the horizontal tunnel will be one of very uniform temperature. The location of the optical shop so far underground was, in fact, done to obtain as uniform an external environment for the laboratory as possible.

According to the current status of the plans for the Optical Sciences Center building, we would expect to have this building in operation within the next eighteen months, although the necessary grant has not yet been received. In regard to the current proposal, in the interim we would propose to use rental space that we already have secured in the Tucson area, and which houses our optical laboratory at the present time. While this environment is not ideal for an optical laboratory, it will nevertheless permit us to do the preliminary testing of the large optical machine included in this proposal, as well as preliminary work on the RZ glass discs that are received prior to the completion of the main laboratory.

B. Status of the U of A 100-inch telescope.

This telescope project was recently made possible by a grant of approximately $1,300,000. from the National Science Foundation under the Science Development Program for the design and construction of the large telescope for the University of Arizona. This telescope is to be erected on the University of Arizona sub-lease on the Kitt Peak National Observatory grounds on Kitt Peak, Arizona. This grant has been matched by the University of Arizona to the extent of approximately $700,000., making a total budged of $2,000,000. for the telescope.

We feel that this project has provided a fine "central project" for our developing Optical Sciences group in that it presents an opportunity to utilize new optical technology while at the same time providing us the means to also extend optical technology in the area of high-resolution telescopes. It is also a "central project" that can be freely talked about as a source of pride to the group since it does not involve the restrictions that often occur in classified programs. We respect the fact that elements of the developed technology are in a rather sensitive area, but at least the end product is "white".

At this date we have issued a bid document on the telescope mounting, with a bid closing date of 14 January 1966. While our original budget for this telescope was predicated upon a telescope that is identical to the Kitt Peak 84" telescope, we have since then elected to use a telescope mounting design that is considerably improved over the Kitt Peak design. The bid document calls for bids on an 84-inch and a 100-inch telescope size.

An assessment of this telescope in context to the interests of basic research in precision optics indicates that the 100-inch size is to be preferred. The reason for this is two-fold: 1), this size of mirror is large enough to accommodate a prime-focus cage for an observer, a factor that is quite important to the question of the design and testing of wide-field high resolution correctors, and 2), it represents a size that is pertinent to interests of the USAF, and sufficient extrapolation over what can be done in the current state-of-the-art to be worth doing.

The additional financial support that would be afforded to the over-all project through this proposal is essential to enable us to both carry out this project in the 100" diameter size and the basic research relevant to the interests of the USAF in the production of zero-coefficient glass lightweight mirror discs and the research related fabrication of these discs into high resolution optical systems.

C. Context of Proposal to OSC and National Interests.

We feel that this proposal covers a task appropriate to the Optical Sciences Center in two regards with respect to the national interests. It develops advanced technology in the center of a graduate and research environment, spreading the enthusiasm and new competence into industrial channels via both new Ph.D.'s as well as technical assistance. It also provides individuals with special significance in classified regards.

## V. RZ GLASS CASTING PROGRAM

A. Problems of ceramic-glasses.

As an introduction to the RZ glass program it is appropriate to review the ceramic-glasses, their properties and some of the problems that have been encountered in the attempts to fabricate light-weight mirrors made of glass-ceramics. A glass-ceramic is initially melted and poured as a glass, and subsequently heat-treated to precipitate a crystalline phase out of the glass melt. While in the glassy state, the glass-ceramics exhibit a thermal expansion coefficient that is typical of common glasses, in the range of 60 to 80 x $10^{-7}/°C$. Upon precipitation of the crystalline phase the glass undergoes a shrinkage of approximately 1% in linear dimensions and at the same time the thermal expansion coefficient drops to a very low value. Final expansion coefficients from approximately -4.0 x $10^{-7}/°C$ up through 0.0 x $10^{-7}/°C$ can be obtained by control of chemical composition and heat treating.

This low expansion coefficient of the glass-ceramic material extends over a very wide temperature range, with as many as three crossings of the zero expansion axis. The zero-crossing points for a typical glass-ceramic would be, for instance, at -200°C, +25°C, and +400°C. The maximum amplitude between these zero crossings would be in the order of 2 x $10^{-7}/°C$. These exceptional temperature characteristics of the glass-ceramics have created wide-spread interest and much effort has gone into the fabrication of mirrors made of these materials that would be suitable for high resolution optical systems.

Two basic problems have been encountered with the glass-ceramics. First the dimensional change during the ceraming process coupled with the invariance of the physical dimensions of the mirror as it is lowered from the ceraming temperature of about 1200°C down to room temperature make it impossible to find any other material of which to make the mold or structure. This requires that one must remove the mold material while the "glassy" disc is at a higher temperature than the ceraming temperature.

The second problem is that it is difficult to fuse the glass-ceramic together to make a structure by the "egg crate" procedure, which has been successfully used for fused silica. While there is a considerable effort currently being directed toward the construction of light-weight mirrors of the glass-ceramics, it does appear prudent to consider alternate material considering problems encountered to date.

B. Properties of RZ glass.

The Development Center of the Owens-Illinois Company in Toledo, Ohio has recently concluded exploratory studies of a glass designated by them as RZ glass. This material is a true glass in contrast to the glass-ceramics that have recently received much attention in regard to zero-coefficient materials, since the RZ glass does not reach a crystalline phase. This new glass also has a low melting point, in the range of ordinary borosilicate optical glasses, rather than in the range of fused-silica glass.

The new RZ glass has rather different physical and handling properties than the glass-ceramics. In regard to the thermal coefficient of expansion, RZ glass has a temperature function that more nearly parallels that of fused silica, with the exception that its coefficient of expansion crosses the zero value at room temperature rather than at -80°C, as in the case of fused silica. While this expansion coefficient zero range is not as wide as for the glass-ceramics, it nevertheless is of sufficient width to afford a considerable operational improvement over fused silica.

In the following table we have compared the physical properties for RZ glass and fused silica. These values have been provided by the Owens-Illinois Company as tentative values for the material, based upon limited experiments made thus far.

TABLE I

Physical properties of RZ glass and fused silica.

| Property | RZ | $SiO_2$ |
|---|---|---|
| Instantaneous thermal expansion to $\pm$ 1 x $10^{-7}$/°C | (0°C) -1.0 x $10^{-7}$<br>(25°C) +0.0 x $10^{-7}$<br>(38°C) +1.0 x $10^{-7}$ | 3.8 x $10^{-7}$<br>5.0 x $10^{-7}$<br>5.5 x $10^{-7}$ |
| Density (gm/cc) | 2.7 | 2.20 |
| Hardness (200 gm load) | 485 (Knoop) | 500 (Knoop) |
| Young's modulus (psi) | 11.6 x $10^6$ | 10.5 x $10^6$ |
| Bulk modulus (psi) | 6.6 x $10^6$ | 5.3 x $10^6$ |
| Poisson's ratio | 0.21 | 0.14 |

The RZ glass material is black in color and opaque throughout the visible spectrum. It does transmit some light in the infrared, and in this sections it has transmission in the ultra-violet; however, in the thicknesses required for telescope mirrors, the glass is essentially opaque to all radiations.

The material has successfully polished to a high degree of polish that is on a par with any normal glass material. The material can be successfully overcoated, silvered, or aluminized as required. Measurement of chemical durability of the glass had indicated excellent resistance to both alkali and acid so there are no anticipated problems from ageing or from the application or removal of overcoated films.

The RZ glass exhibits working conditions similar to borosilicate glasses, so that normal glass-making techniques should be readily applicable. This would imply that there should be no long developmental stages as has been necessary in the handling and fabrication of the glass-ceramics. The melting of this material should be similar in complexity to Pyrex. While no large melts of this glass have been done to date, there are no difficulties apparent in this area.

The fact that the RZ glass has a rather parallel rate of change of coefficient to that of fused silica means that it is possible to construct mold materials that will follow in expansion that of the glass contained in the mold. The mold, therefore, does not have to be removed from the glass during the annealing period, but can be removed when the glass has reached room temperature. In this manner, the construction of a ribbed or light-weight mirror would be similar to the case if one wished to make the mirror out of such a material as Pyrex.

If the mold material is made of a relatively light-weight foamed silica, such as can be produced by the slip-formed method of casting silica, then the core material would be relatively friable and easily removed from the glass structure by standard techniques, such as sand blasting.

The RZ glass appears to have the possibility for adhesive fabrication, as in the case of fused silica. We could therefore anticipate the attachment of a continuous glass plate to the rear of a cast ribbed glass structure by heating the two elements to a point at which the surfaces become sticky. It would appear, therefore, that the RZ glass has enough different fabrication methods to offer several new approaches to the construction of light-weight mirrors of large size suitable for space applications.

The fact that RZ glass is black and opaque presents a problem in the quality control of the anneal of discs during manufacturing. One generally relies upon polarization tests to evaluate the residual stress in a mirror after anneal. In the case of RZ glass, we would have to rely on other techniques. The fact that the material does transmit infrared light means that we could possibly measure the strain of the blank by utilizing infrared light and appropriate polarization detectors. This procedure, however, would be much more complicated than is now the case with transparent materials.

The second testing procedure that could be evaluated, and that we feel would be adequate, would be to place an ordinary optical glass blank in the anneal oven during the processing of the RZ glass blank. It is well known that low-coefficient materials generally have much lower residual anneal stresses than do normal optical glass materials, due in part, to the fact that the dimensional changes in the material are quite small during the annealing process. Optical glasses, on the other hand, are very sensitive to the anneal and show large residual stresses if the annealing has not been properly done. It would therefore appear possible to calibrate the process with a glass that is transparent and more sensitive to the anneal cycle than the RZ glass and later use this test as a means of production quality control for the product.

One of the most sensitive tests for residual strain in an optical blank is to cut the blank in half after optical processing. If the blank has low strain, the sawing process will not disturb the figure on the polished surface. If the glass is strained, the cut will release the strains and the surface of the glass will warp.

C. Fabrication of the smaller discs.

In regard to the production of the mirror discs incorporated in this proposal, we would initially start with two 30" solid discs of RZ glass, to be cast and annealed with existing equipment at Owens-Illinois. As soon as the 30" mirrors are in the anneal oven we would procede to cast the two 40" solid discs. The time alloted from the start of work on each size of solid discs to the completion, ready for delivery, is estimated at two months each.

Following the successful casting of these two sizes of solid mirrors, we would propose to procede to a simple rib structure in approximately a 40" diameter size. The time required for the construction of the ribbed mold, the casting and annealing estimated to be three months.

Approximately two months after starting the 40" ribbed mirror it would be appropriate to begin work on 60" ribbed mirror. This mirror would have a structure similar to that proposed for the 100" size, except that the mirror would be limited to one row of six support sockets. We estimate that four months would be required to carry out this phase of the project.

Since the 100" mirror requires a rather large mass of glass, about 5,000 lbs., the production of approximately 25-24" diameter discs of RZ glass cullet would be initiated approximately three months after the start of this project.

D. Fabrication of the 100-inch Disc.

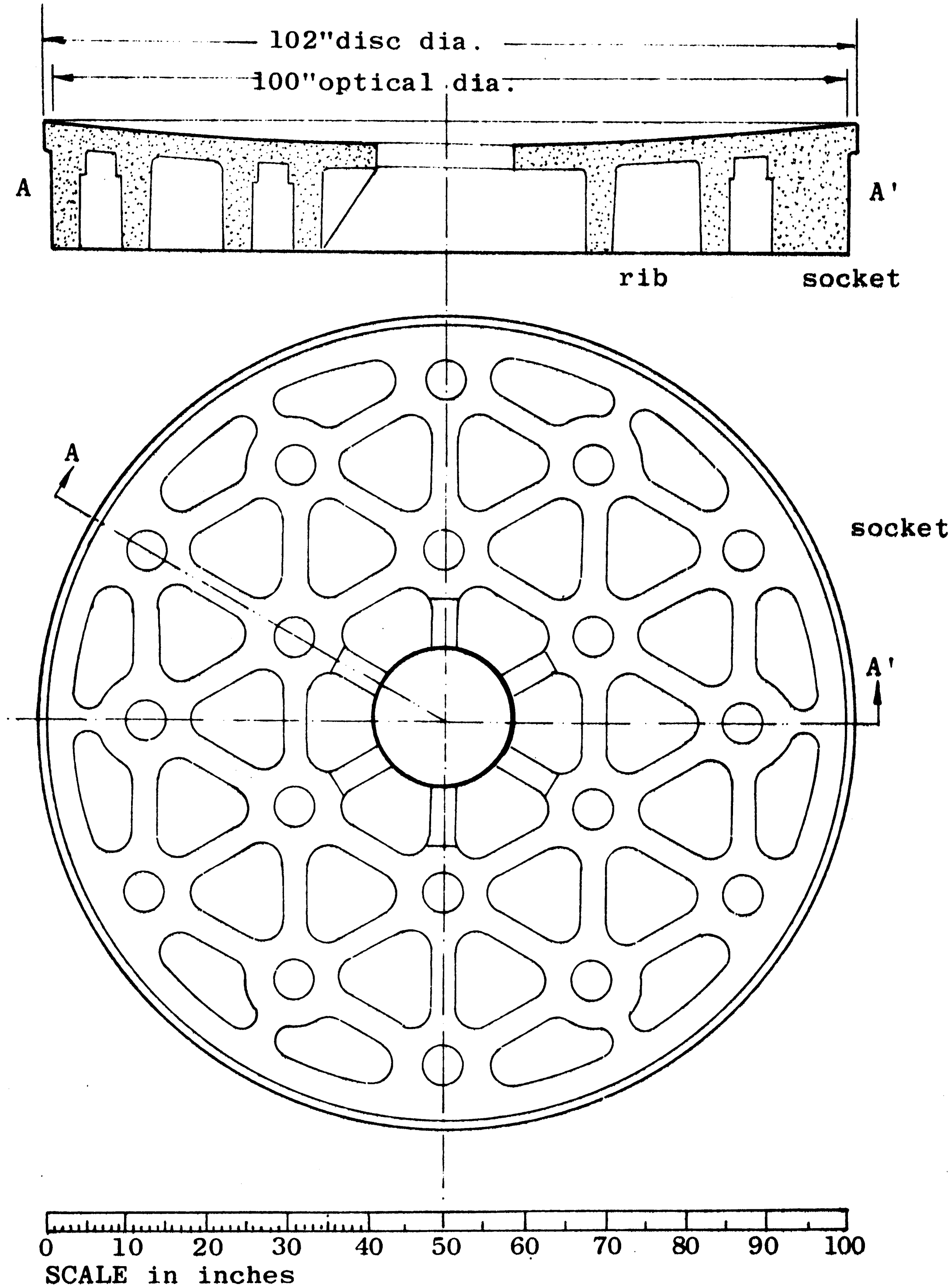
The following description is intended as a general outline of the procedures that would be followed in the casting of the 100-inch ribbed disc of RZ glass. The steps below are taken from the experience with the fabrication of the 84-inch Kitt Peak ribbed disc of Pyrex, since the handling characteristics should be approximately the same.

The mold with the shape of the rib structure for the 100" mirror would be made of foamed fused silica, or an equivalent. The cores can be assembled by bolting the cores to the floor of the mold, as is done when individual fire brick cores are used. The newer processes of slip-formed silica, however, offer the opportunity to cast the rib structures as an integral part of the glass tank.

1) Mirror design.

The tentative design of the rib structure for the 100" RZ mirror blank is shown in Figure 2.

As previously mentioned, this design is a relatively conservative design. A study of ribbed-mirror structures was made several years ago by Bowen and Meinel as part of the design study for the Kitt Peak 84-inch telescope. A number of designs were evolved at this time; however, this design proved to be the stiffest design for the weight factor that was readily adapted to manufacture. The requirement for support sockets does weaken the structure a bit, but they are necessary to solve the problem of the six intersecting rib arms. It is anticipated that the successful casting of a mirror of this relatively simple rib configuration would pave the way for later castings of a more complex nature that might be more specifically oriented to space applications.




PROPOSED RIB DESIGN FOR THE 100-INCH RZ GLASS MIRROR

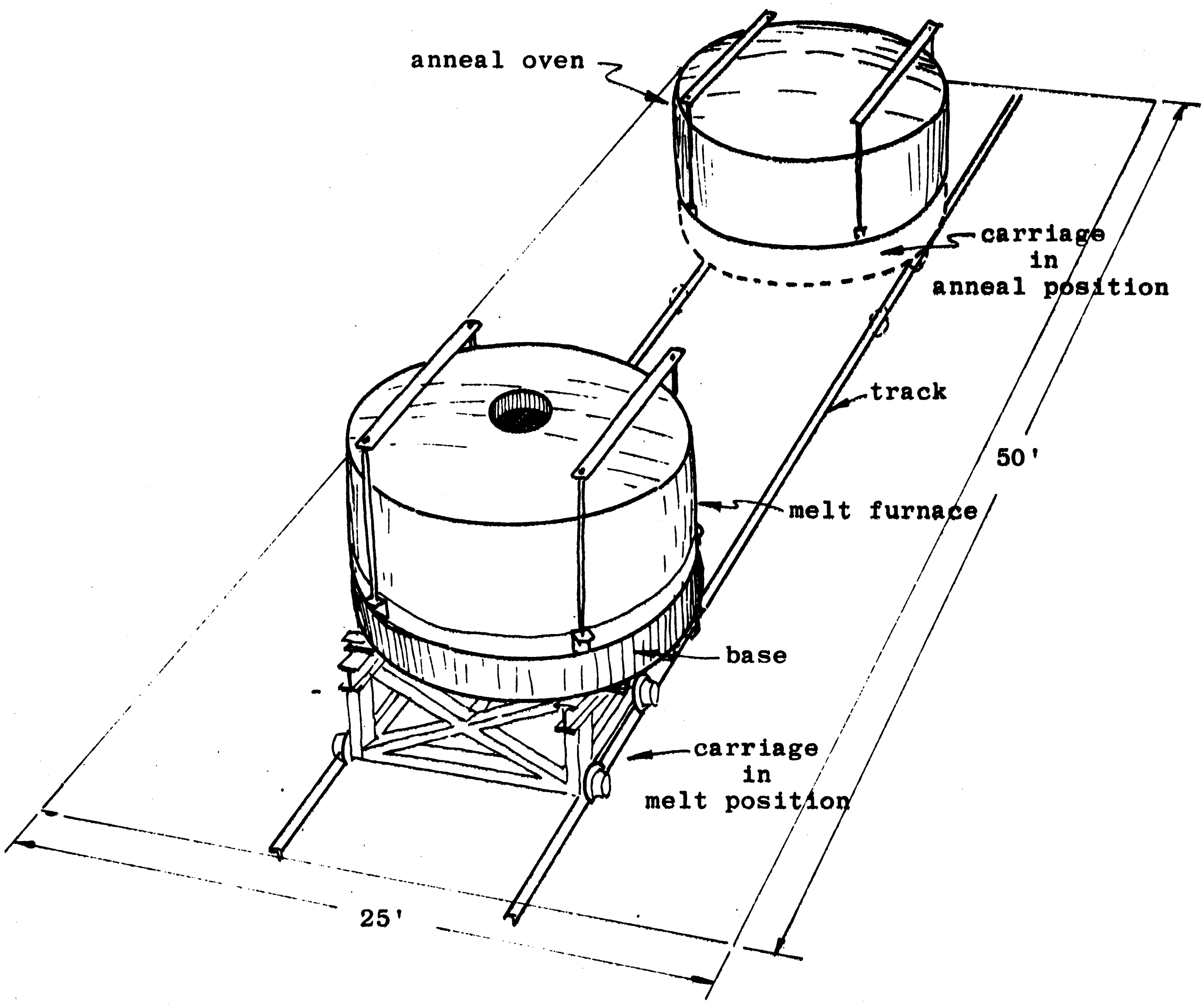
The front plate of the mirror would be made to finish to approximately 3" thickness. The ribs would be approximately 2-3/4" wide and 11 inches deep. The outer rim diameter would also finish to approximately 3" thickness. The design shown is a rather conservative one but one that will adequately demonstrate the feasibility of the construction of ribbed cast structures of RZ glass.

The proposed rib structure gives us several options with regard to the mountings to be used. The mirror can be mounted, for example, by means of counter-weighted supports using the 18 support sockets. On the other hand, the mirror can also be mounted on an air bag support that picks up the weight of the mirror via the back face of the rib structures.

The estimated weight factor for a mirror of this design is approximately 40% of that for a solid mirror of the same external dimensions. We have considered several alternate rib designs for mirrors of this type; however, this design seems to adequately combine a conservative structure along with the opportunity to evaluate both the RZ glass material and the flexibility that is intrinsic in the new type of stationary table polisher.

2) Shop layout.

The proposed shop layout for the construction facility of the 100" mirror is shown in Figure 3. The shop area required for this layout is approximately 25 ft. wide and 50 ft. long, with two tracks laid in the floor to carry the carriage. The necessity for two structures is that the gas fired heat used to melt the mirror does not provide sufficient control of the temperature for the anneal cycle. The anneal oven hood is equipped with electrical heating for the required control during the anneal cycle. The shop in which these two structures are located would be equipped with an overhead mobile crane to facilitate the lifting of the melt furnace hood and the lowering of the anneal oven hood. The structure in the lower part




SHOP LAYOUT FOR 100-INCH RIBBED MIRROR

of Figure 3 is the melting furnace, shown with the mirror mold and carriage in place. The upper structure is the anneal oven hood. The dotted line structure represents the position that the mirror mold and carriage have during the anneal cycle.

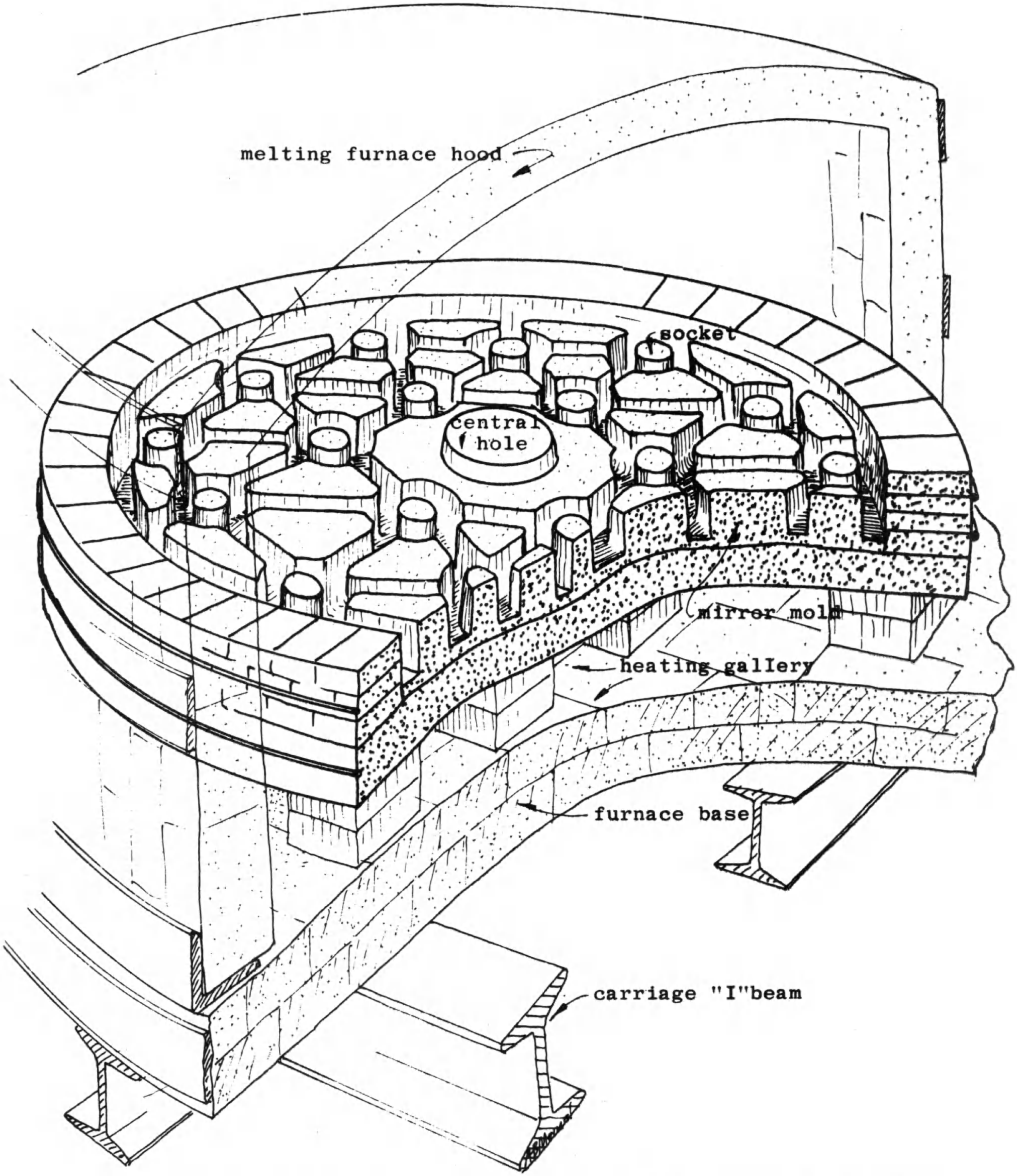
A third location is required in the processing of the mirror, not shown in Figure 3. This is the location where the cooled mirror and mold can be disassembled and the fire brick chipped off of the glass mirror. It is advisable to be able to drape this area with tarpaulins (see Fig. 6), since it is generally necessary to use sand blasting to remove all of the mold material from the glass. After the first rough removal of the fire brick from the mirror, the mirror can be mounted on wooden planks so that personnel can get beneath the mirror as well as above it. The final work on the mirror is done with the ribbed structure facing upward, so that the workmen can sand-blast out the last remnants of the fire brick attached to the inside surfaces of the ribbed structure.

3) Melting furnace and mirror mold.

A cutaway view of the melting furnace is shown in Figure 4. This figure shows a portion of the carriage I-beam on which the furnace base is constructed. The two carriage I-beams are in turn spanned by several smaller I-beams that provide a support for the furnace base.

The ceramic base of the mold structure is carried on this carriage throughout all of the melting and anneal operations. This ceramic base provides a structural and thermal base for the mirror mold.

The mirror mold is supported off the furnace base floor on a number of fire-brick columns to provide a gallery system to distribute heat around the mold. The gas heat is primarily directed into the heating gallery and then heats the entire system from beneath. In this manner the mold is generally hotter than the glass that is supported on the mold.




CUTAWAY VIEW OF MELTING FURNACE WITH 100-INCH MIRROR MOLD

The mirror mold, shown in Figure 4, is constructed of a number of parts, the base being separate from the mold structure and from the peripheral ring, to facilitate the dismantling the mold from the completed glass disc. The mold is shown as an integral structure, as might be cast by the slip-cast silica method. An alternate method, and one that was highly successful in the case of the 84" mirror, is to bolt each of the core structures to the floor of the mold. In this case it is necessary to use bolts that will not become plastic at the temperatures required to hold the glass during the melting stages. The furnace base and the mold are then covered by a melting furnace hood that can be raised off of the structure at the time that the mirror is transferred to the anneal oven.

4) Anneal furnace hood.

The annealing furnace is located adjacent to the melting furnace. The top of the anneal furnace uses electrical heaters as the source of heat during the anneal cycle. The anneal furnace is pre-heated prior to the transfer of the re-solidified RZ glass in the mirror mold. It should be approximately in equilibrium with the lower section of the mold when the mirror and the lower portion of the furnace are transferred via the carriage to the position of the anneal furnace. (See Fig. 3) The upper portion of the anneal furnace is then lowered onto the lower portion of the mold structure and the anneal cycle is then started.

5) <u>The cullet method</u>.

The RZ glass to be cast into the mirror is mounted upon the rib mold in chunks of various sizes, called "cullet". The proper weight glass is piled into the mold as required to make the finished mirror.

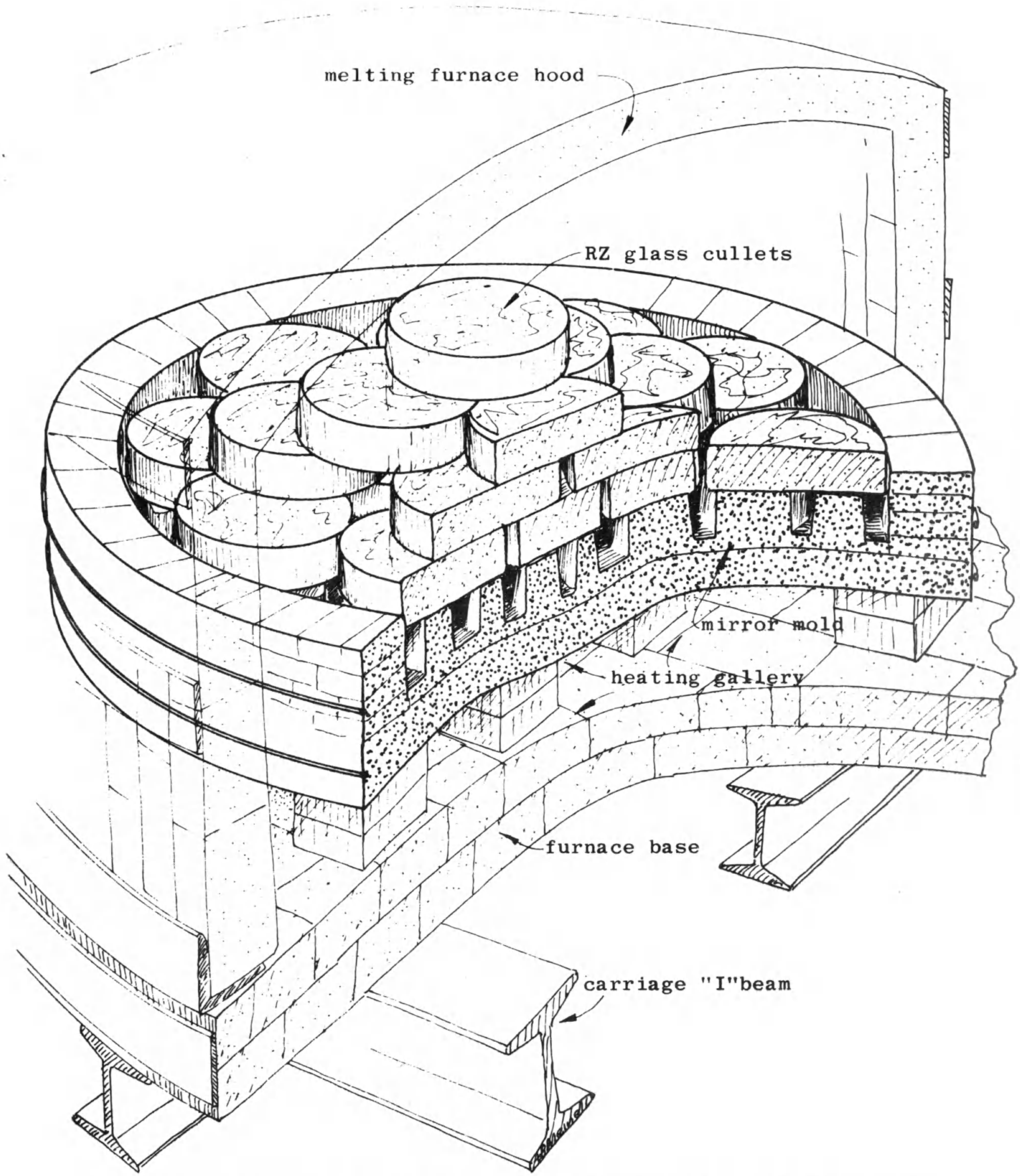
This glass is stacked upon the mirror mold in the approximate shape of the pyramid with the highest point at the center of the mold. Cullet consists of refined RZ glass that has been cast for convenience into the shape of circular discs. Any reasonably large size shape of glass is suitable for the cullet; however, the number of pieces of glass should be kept reasonably small in order to reduce the number of entrapped bubbles during the melting process. During the melting phase the glass cullet discs melt from the periphery and flow down into the mold, gradually filling the mold to the finished mirror level.

Figure 5 shows the cutaway view of the melting furnace after it has been loaded with the RZ glass cullet. The RZ glass cullet, for instance, could consist of approximately 125 discs 24" in diameter and 6" in thickness, or the equivalent number as larger size discs to make up the required load of approximately 5000 lbs. of glass.

6) Temperature schedule.

A temperature schedule for the melting and annealing for the 100" mirror is shown in Figure 6. Both the temperatures and the time in Figure 6 are only crude estimates.

The temperature in the melting furnace initially is raised to approximately 1000°C and held at this point for two days, requiring approximately four days total elapsed time. After the conditioning is completed the temperature of the furnace is raised to approximately 2200°C and held at this temperature during the melting phase. After the RZ glass cullet has been fully melted, the molten mirror mass is kept at melt temperature for a reasonable length of time in order to remove the bubbles from the glass and accomplish the final fining of the glass. The temperature is then dropped in the melt furnace to approximately 1500°C prior to the transfer of the mirror from the melting furnace to the anneal furnace. At the transfer temperature the glass has already set in the mirror mold.




CUTAWAY VIEW OF MELTING FURNACE-RZ GLASS CULLET LOAD IN PLACE

Prior to the transfer of the mirror, the anneal oven is brought up to temperature with an initial hold at approximately 1000°C to condition this furnace. The false floor is removed from under the furnace hood and the mirror mold base and carriage are transferred via the rails in the floor of the shop to a spot directly under the anneal hood.

During the anneal cycle the temperature in the anneal oven is gradually reduced at a rate that will assure the release of the strains that tend to build up in the mirror disc as the temperature of the entire structure is lowered. When the temperature of the glass disc has been lowered to a point where the viscosity of the glass becomes so high that further annealing is negligible, the temperature can be lowered at a more rapid rate down to room temperature.

The time scale in Figure 6 is divided such that Sundays, indicated by the s, occur at non-critical phases. The transfer of the disc occurs at approximately 12 days after the start of the cycle, and the final cooling stage at approximately 26 days. The total elapsed time from the start of the production of the mirror to the return of the finished mirror to room temperature is estimated at 39 days.

The finished mirror and mold are then placed in an enclosed area for the removal of the silica mold material from around the mirror. The mirror is initially placed face up and the peripheral discs removed. If the mold has been properly constructed these bricks remove rather readily from the mirror, leaving only a small amount of the silica brick adherred to the glass. The mirror is then turned with its front face down and the back surface of the mirror mold then removed.

The final removal of the cores must be done using sand blast methods. Considerable care is required at this stage because of the natural pocketing action of the sand-blast when working inside a cavity. The entire periphery

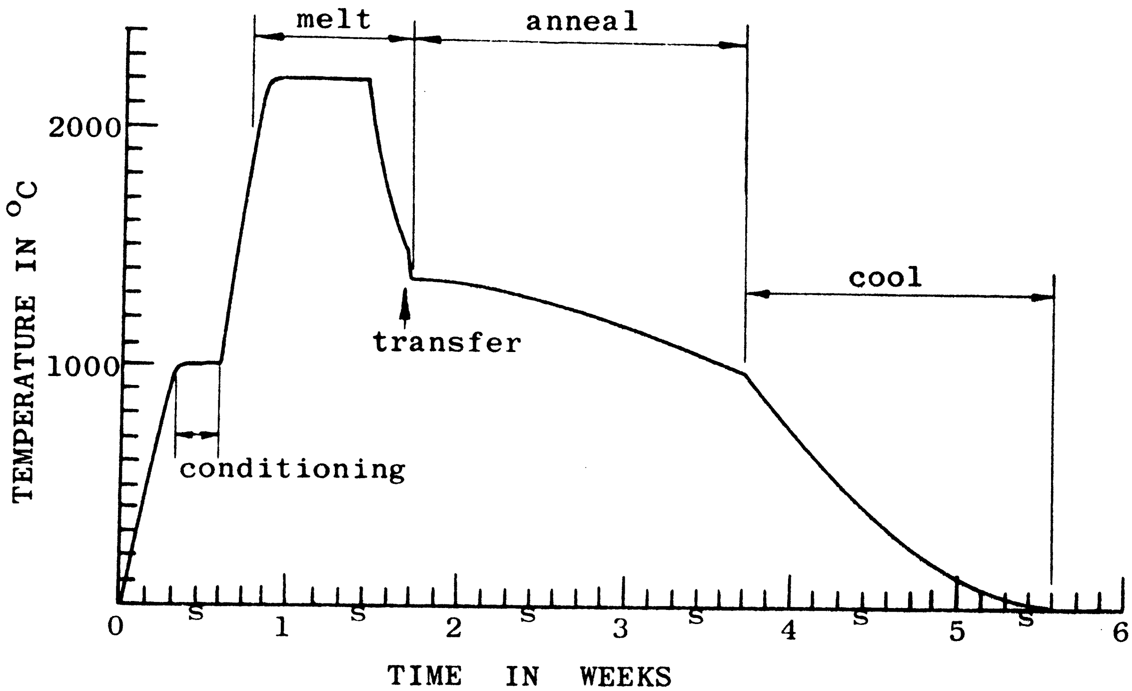



Figure 6. Typical temperature cycle for the fabrication of a 100-inch ribbed mirror disc.

Figure 7. The 84-inch Pyrex mirror disc after sand-blasting for removal of mold material. (Corning Glass Works, Corning, N. Y.)

of the mirror should then be sand-blasted to remove the remaining silica mold material down to a point where optical diamond milling of the exterior glass surfaces will remove the transition of glass and silica down to the finished disc dimensions.

The appearance of a ribbed disc after core removal is shown in Figure 7. The roughness of the surface is inconsequential since these surfaces are finished by diamond milling during processing of the blank. Note the draped protective screens remaining from the sand-blasting operations.

7) Time Schedule.

The time schedule for the entire program covered by this proposal is shown in Table II.

Table II

TIME SCHEDULE