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EXPLORATORY DEVELOPMENT TO SHOW TECHNICAL FEASIBILITY OF AUTOMATIC FABRICATION OF SPECTACLE LENSES IN THE FIELD

J. T. CELENTANO, M.D.
Q. Y. CHANG
M. GRESHES
G. N. HOOVER, PH.D.
E. C. KELLY

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This report covers effort conducted under four tasks: Materials Development; Design Analyses; Breadboard Studies; and Design of Pre-Prototype/Breadboard Model. Materials development was directed toward refining the processing of polycarbonate materials, ~~including inspection and~~ evaluation of raw polycarbonate resin ~~from different batches~~; ~~the further evaluation of~~ and polycarbonate thermosetting coating materials; and developing processing techniques for ~~these~~ coatings. Design analyses have involved the development of theoretical and empirical data for fabricating lenses and programming the computer. Shapes and weights of each sphere, cylinder, and spherocylinder have been calculated and are being verified empirically. Breadboard studies have been directed toward mold and mold assembly characteristics and the development of a series of laboratory molding systems. for ~~determining design characteristics.~~ Design efforts have been reducing the information generated in the previous tasks to a practical conceptual model which will lead to final design trade-offs. ~~and final design.~~

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EXPLORATORY DEVELOPMENT TO SHOW TECHNICAL FEASIBILITY OF AUTOMATIC FABRICATION OF SPECTACLE LENSES IN THE FIELD

THIRD TECHNICAL SUMMARY REPORT

J. T. CELENTANO, M. D.
Q. Y. CHANG
M. GRESHES
G. N. HOOVER, PH. D.
E. C. KELLY

30 April 1972

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LIFE SYSTEMS RESEARCH INSTITUTE
1900 Avenue of the Stars, Suite 755
Los Angeles, California 90067

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FOREWORD

This is the third technical summary report of a study entitled "Exploratory Development to Show Technical Feasibility of Automatic Fabrication of Spectacle Lenses in the Field." The report is submitted by Life Systems Research Institute to the U.S. Army Medical Research and Development Command under Contract No. DADA17-71-C-1006, 15 August 1970, and in accordance with the Delivery "Item 2" of the Life Systems Research Institute proposal dated 1 April 1970 and revised proposal dated 4 September 1970.

The report covers the period 15 August 1971 to 14 February 1972. Effort was conducted under four tasks: Materials Development; Design Analyses; Breadboard Studies; and Design of Pre-Prototype/Breadboard Model. The work was performed by the staff of Life Systems Research Institute at its offices and laboratory and model shop in Los Angeles and by Life Systems Research Institutes' subcontractor, M. Greshes and Associates, at his facility in New York.

Dr. J. T. Celentano is the Principal Investigator and Project Manager for the study. Mr. Q. Y. Chang is the Project Engineer. Mr. M. Greshes is responsible for material development.

ABSTRACT

This is the third technical report of a study entitled "Exploratory Development to Show Technical Feasibility of Automatic Fabrication of Spectacle Lenses in the Field," U.S. Army Medical Research and Development Command, Contract DADA17-71-C-1006, 15 August 1970. The report covers effort conducted under four tasks: Materials Development; Design Analyses; Breadboard Studies; and Design of Pre-Prototype/Breadboard Model. The work was accomplished during the period 15 August 1971 to 14 February 1972.

Materials development was directed toward refining the processing of polycarbonate materials, including inspection and evaluation of raw polycarbonate resin from different batches; the further evaluation of polycarbonate thermosetting coating materials; and developing processing techniques for these coatings.

Design analyses have involved the development of theoretical and empirical data for fabricating lenses and programming the computer. Shapes and weights of each sphere, cylinder, and spherocylinder have been calculated and are being verified empirically.

Breadboard studies have been directed toward mold and mold assembly characteristics and the development of a series of laboratory molding systems for determining design characteristics.

Design efforts have been devoted to reducing the information generated in the previous tasks to a practical conceptual model, which will lead to final design trade-offs and final design.

INTRODUCTION

This is the third technical summary report and, as such, represents the progress accomplished during the third six-month period of the project. Much of the effort has been devoted to engineering analyses and trade-offs, engineering development, breadboard studies, and the development of a data pool for programming the final breadboard system.

During this period the subcontract with M. Greshes and Associates was completed. The majority of subcontract effort during this reporting period involved more complete evaluation of coating materials and coating processes. In addition, other coating materials were evaluated and studied by LSRI. As this represents a fairly complete assessment, a discussion of the coating evaluation is presented in this report in some detail.

The second technical summary report caused some confusion due to terminology used and should be clarified. The breadboard study system discussed referred to the laboratory or bench system developed for the breadboard studies task. This laboratory system, discussed at length in the second technical summary report, will provide the necessary data for the design and operational characteristics of the final deliverable item: the pre-prototype/breadboard system. The laboratory unit is now referred to as the laboratory or bench system and only the final deliverable item will be referred to as the breadboard system. Much of this laboratory system will be used without major modification in the final deliverable breadboard system.

The extent of the laboratory system fabrication and utilization is essential for the development of the raw data necessary for programming the final deliverable breadboard system. For example, each different lens fabricated will have its own characteristic thickness and weight, and its own heat and pressure cycle. While the thickness and weight can be theoretically determined, pressure and heat cycling must be empirically determined. Therefore, it is necessary to fabricate several of each lens prescription. As this amounts to several thousand lenses, lenses are being fabricated as rapidly as possible to provide design data and program data for the final breadboard system.

LENS COATINGS

The question of abrasion resistance with respect to plastics is one of degree. In general, plastics are soft when compared to glass. In fact, the very nature of plastic that makes it a desirable material for ophthalmic lenses allows it to be abrasion prone. Were plastic to become as hard as glass it would be as brittle also, and this brittle nature of glass makes it unacceptable for a prescription lens. This being the case, one realizes that abrasion resistance is a problem with any plastic.

Measure abrasion resistance on a scale of 1 to 100 with crown glass at 100. Plastics would be bunched at the low end with polycarbonate at 25, methyl methacrylate (acrylic or plexiglass) at 30, and allyl diglycol carbonate (CR-39) at 35. Since CR-39 is the only commercial prescription material in use today it should serve as the basis for abrasion resistance comparison with crown glass as a distant but desirable goal. On this basis, any plastic substrate should be treated (or coated) to make it less abrasion prone.

Plastics are also generally soluble in a variety of organic solvents and a coating is desirable to improve solvent resistance. Polycarbonate is soluble in aromatic and chlorinated hydrocarbons. Contact with these solvents will cause crazing or distortion of the surface with its resultant effect on the optical properties of the lens. Aromatic hydrocarbons are ubiquitous and the probability of contact is great, hence the lens must be protected from attack. Chlorinated hydrocarbons are generally associated with the aersol insecticides, which find wide usage in combat zones, and the probability of contact is also great.

The basic requirements for a coating material for polycarbonates are:

- Approximately the same index of refraction
- Insoluble in most organic solvents
- Abrasion resistant
- Easily applied and cured
- Strong adhesion to polycarbonate
- Basically colorless

Several classes of coating materials having most of these qualities are available and suitable for coating polycarbonates. They include melamines, epoxies, siloxanes, urethanes, polyvinly alcohols, and combinations and variations of these. Several proprietary compounds are available or under development for polycarbonate coating. Examples are "ABCITE" from DuPont, "GLASS RESIN" from Owens-Illinois, "LEXCOATE" from Ball Chemical Company, "CYMEL-300" from American Cyanimide, "Coating E-397" from Mobay Chemical and "Coating MR-4000" from General Electric.

EVALUATION

Epoxy, Melamine and Combination Coatings

Over 100 epoxy, melamines and epoxy-melamine combinations have been tested and evaluated. Testing consisted of cutting methyl methacrylate sheets into 1" x 3" strips, cleaning with a suitable agent such as ethanol and submerging halfway into a coating formulation. When a formulation showed a more superior degree of abrasion resistance on methyl methacrylate, that formula was then tested on a compression molded polycarbonate lens, using the same "half coated" technique.

The coated substrate was then air dried and cured at temperatures ranging from room temperature to 300°F and cycles from 20 minutes to 24 hours. Fixed ratios of melamine/epoxy were used, these ratios based on previous experience. Ratios were then varied or used in rates recommended by the manufacturer according to their formulations, for example: Marblette #655 with melamine (CYMEL 300).

Each strip of methyl methacrylate was scratched three times with a specific abrasive across the uncoated portion, across the boundary and on through the coated portion. In this manner, it could easily be ascertained whether the coated portion was in any way superior to that of the uncoated portion and to what degree.

On many occasions, a particular solvent was found to be incompatible and a series of substitutions was necessary before an evaluation was possible, for example: with Ciba #502, ethanol and Bee Thinner was replaced with toluene.

Occasionally, cure times and temperatures which were recommended by an epoxy manufacturer were not sufficient and the coating would remain tacky, allowing no evaluation, for example: Marblette Epoxy #658 with Marblette Catalyst.

Other formulations caused a severe stippling effect, for example: Stycast 1266, Ciba 502 and Araldite CY183.

Still others were translucent on cure, rendering them useless for our purpose. Repeated alterations in formulations, in most cases, failed to resolve this difficulty, for example: Marblette #602 with CYMEL 300.

After a preliminary screening of the various materials which showed a better than methyl methacrylate abrasion resistance, variations in formulation were tried to achieve the maximum result, for example: Araldite 6010 with Araldite Hardner and CYMEL 300. In the case of Araldite 6010, additives did not improve abrasion resistance and, in fact, the coating was better without additives. Lower temperatures and longer cures improved the coated surface. The results of the epoxy/melamine tests are summarized in Table I.

The results of this evaluation can best be summarized by the statement that most of the epoxy-melamine coatings are capable of protecting the lens against abrasion. Marblette's epoxy #655 with melamine, #659 without melamine, and Ciba's epoxy #6010 with and without melamine all had better abrasion resistance than methyl methacrylate. However, when these coatings were compared to CR-39 using an abrasive scratch test, only Ciba epoxy #6010 was as resistant to abrasion as CR-39. These findings prompted efforts with other coating materials.

Siloxane Coatings

ABCITE is a proprietary siloxane type coating material owned by DuPont. The licensing of the process for use of this coating is prohibitive, and the material has only been evaluated on sample lenses coated by DuPont. The best formulation available cures in one hour at 300°F and appears to have an abrasion resistance about 30% better than CR-39.

Since it is known that ABCITE is composed of polysilic acid and copolymers of fluorinated monomers several formulations of ethyl silicate were prepared and evaluated according to the patent literature. The results of these evaluations are given in Table II.

Materials available were evaluated in much the same way as epoxy-melamine coatings in that 1" x 3" strips of methyl methacrylate were coated using only one-half of each strip. When the coating was found to have superior abrasion resistant qualities, those same formulations were tested on polycarbonate compression molded lenses. Each coating was evaluated by means of a special eraser, scratching across the uncoated portion, through the boundary and on through the coated portion, using three scratches.

Formulations used were in accordance with the patent literature with the only variation being in the method of application, cure time and temperature.

In most cases, portions of each formulation required aging varying from 4 1/2 hours to 8 days.

Coating under patent #2,404,357 called for curing in the compression molding machine under pressure. While this would seem attractive from the standpoint of a compression molding system, there were numerous problems inherent in the process. Lens was dip coated for two minutes in coating and air

TABLE I
EPOXY - MELAMINE FORMULATIONS

MATERIAL	USE OF SOLVENT	% EPOXY USED	CURE TIME	CURE TEMP (F)	EVALUATION		
					BETTER	EQUAL	POOR
Marblette 655	S	100%	1 hr.	230			X
	S	33%	55 min.	280	X		
	S	25%	45 min.	280	X		
	S	50%	55 min.	280	X		
Stycast 1269	-	100%	1 hr.	280		X	
	-	100%	4 hrs.	250		X	
	S	100%	50 min.	280		X	
	S	75%	50 min.	280		X*	
	S	75%	4 hrs.	250		X*	
Marblette 658	S	100%	45 min.	280		X	
	S	30%	45 min.	280		X	
Marblette 659	-	100%	50 min.	280	X		
	S	100%	50 min.	280		X	
	S	30%	50 min.	280		X	
Marblette 658/659	-	100%	45 min.	280		X	
	S	100%	45 min.	280		X*	
	S	50%	45 min.	280		X*	
Ciba 502	-	100%	2 hrs.	212		X	
Ciba 502 (Methacrylic acid added)	S	75%	2 hrs.	212		X*	
Ciba 502 (Silicone added)	S	75%	2 hrs.	210		X*	
Ciba 502 (Solvent altered)	S	75%	2 hrs.	210		X	

*Indicates cloudiness or yellowing

TABLE I (Continued)

MATERIAL	USE OF SOLVENT	% EPOXY USED	CURE TIME	CURE TEMP (F)	EVALUATION		
					BETTER	EQUAL	POOR
Ciba ECN 1273	S	30%	45 min.	284		X*	
Ciba EPN 1139	-	100%	2 hrs.	212		X*	
	-	100%	2 hrs.	280		X*	
	-	100%	8 hrs.	300		X*	
	S	100%	2 hrs.	212		X*	
	S	100%	2 hrs.	280		X*	
	S	100%	8 hrs.	300		X*	
	S	60%	2 hrs.	212		X*	
	S	60%	2 hrs.	280		X*	
	S	60%	8 hrs.	300		X*	
Lexcote G3327	-	100%	30 min.	140		X	
	-	75%	45 min.	140		X	
	S	75%	45 min.	140		X*	
Lexcote G3327 (Silicone added)	S	75%	45 min.	140		X*	
Stycast 1266	-	100%	2 hrs.	240		X	
	-	100%	24 hrs.	room temp			X
	S	100%	45 min.	240		X	
	S	100%	2 hrs.	240		X*	
	-	75%	35 min.	240			X*
	S	75%	2 hrs.	240	X*		
Stycast 1266 (Silicone added)	S	75%	2 hrs.	240	X*		
Stycast 1266 (Methacrylic acid added)	S	75%	2 hrs.	240		X	

*Indicates cloudiness or yellowing

TABLE I (Continued)

MATERIAL	USE OF SOLVENT	% EPOXY USED	CURE TIME	CURE TEMP (F)	EVALUATION		
					BETTER	EQUAL	POOR
Stycast 40A	-	100%	2 hrs.	210		X	
	S	100%	2 hrs.	210		X*	
	S	80%	2 hrs.	210			X
Stycast 40A (Varied Catalyst)	-	100%	2 hrs.	210			X
	S	100%	2 hrs.	210			X
	S	80%	2 hrs.	210			X
Marblette 6164	S	33%	1 hr.	280		X*	
	S	25%	1 hr.	280		X*	
	S	50%	1 hr.	280		X*	
Marblette 602	S	33%	1 hr.	280		X*	
	S	25%	1 hr.	280		X*	
	S	50%	55 min.	280		X*	
Araldite CY183	S	100%	60 min.	176		X	
	S	100%	16 hrs.	248		X	
	S	50%	60 min.	176		X	
	S	50%	16 hrs.	248		X	
	-	100%	60 min.	176			X*
	-	100%	16 hrs.	248			X*
	-	80%	4 hrs.	248			X*
Araldite 6010	S	100%	6 hrs.	212	X		
	S	100%	2 hrs.	212	X		
Araldite 6010 (Silicone added)	S	80%	6 hrs.	212	X*		

*Indicates cloudiness or yellowing

TABLE I (Continued)

MATERIAL	USE OF SOLVENT	% EPOXY USED	CURE TIME	CURE TEMP (F)	EVALUATION		
					BETTER	EQUAL	POOR
Araldite 6010	S	80%	6 hrs.	212	X		
Araldite 6010 (Methacrylic acid added)	S	80%	6 hrs.	212	X		
	S	80%	1 hr.	280	X		
Araldite 6010	S	80%	1 hr.	280	X		
	S	80%	2 hrs.	250			X
	S	80%	2 hrs.	250		X	
	S	100%	2 hrs.	280		X*	
	S	100%	2 hrs.	280	X		
	S	80%	2 hrs.	280		X*	
	S	80%	2 hrs.	280		X	
	S	100%	2 hrs.	250	X		
	S	80%	2 hrs.	250		X	
	S	60%	2 hrs.	250			X*
	S	50%	2 hrs.	250			X*
Eccogel 1265	-	100%	5 1/2 hrs.	200			X*
	S	60%	5 1/2 hrs.	200			X*
CPC16	-	100%	12 hrs.	200			X
	S	100%	12 hrs.	200			X
	S	50%	12 hrs.	200			X
M700	S	70%	30 min.	150	X*		
	S	70%	30 min.	300	X*		
Eccobond 24	S	100%	1 hr.	212			X
	S	70%	1 hr.	212			X
VAGH (vinly resin)	S	90%	20 min.	250		X*	

*Indicates cloudiness or yellowing

dried 8 minutes. Lens was then inserted in proper mold and placed in compression molding machine at 200°F under 1100 pounds pressure. When temperature returned to approximately 190°F, heat was turned off and platens allowed to cool for 25 minutes. Pressure was released and mold removed. Using the aforementioned scratch test, abrasion resistance was found to be better than methyl methacrylate or polycarbonate, however, the coating peeled.

While there was somewhat better abrasion resistance, in no case was it any better than CR-39. Attempts to find or develop a primer to prevent peeling or provide better adhesion of the coating material was not successful.

The Owens-Illinois Glass Resin polymer is so named because of its glass-like appearance. When cured, it is a thermoset silicone which will not soften when heated and is insoluble in all common organic solvents. Unlike most thermosets, the Glass Resin has no exotherm and heat must be applied to cure the coating resin. Glass Resin Type 650 has exceptional light transparency with an ultraviolet cutoff below 1900A. A coating thickness of 0.5 mil or less is recommended.

Glass Resin coatings are chemically resistant to concentrated and dilute acids and bases such as: hydrochloric acid, sulfuric acid and sodium hydroxide for 24 hours at room temperature. Solvents such as acetone or other ketones will soften or permeate the coating but when removed from the solvent, the coating becomes hard once again.

Properly cured coatings are quite transparent or glass-like in appearance and are easily cleaned. Coatings 0.5 mil thick will have a sward hardness of 35-50 or a pencil hardness of the H scale of 7H and above.

Glass Resin Type 100 coatings 0.5 mil or less will withstand 180°C flexibility over a 1/8" mandrel and remains intact on metal elongations of 10 percent based on the General Electric drop test. Glass Resin 650 coatings will have similar flexibility if applied at a thickness of 0.2-0.3 mil.

The curing of the Glass Resin coating is determined by the thickness of the coating and the nature of the substrate. The cure is a time, temperature relationship. The criteria for cure is insolubility as determined by wiping the coating with an acetone saturated cloth and pencil hardness. The cure cycle for plastic substrates varies from 15 minutes to 16 hours depending upon the temperature of the catalyst used, and the degree of hardness required. Some glass resin test results are shown in Table II.

TABLE II

SILOXANE - TYPE COATINGS

MATERIAL	RATIO OF ACTIVE COMPONENTS	CURE TIME	CURE TEMP (F)	EVALUATION BETTER	EQUAL	POOR
Ethyl Silicate and Polyvinyl Acetate PAT. 2,404,357	12.5 gms to .7 gms and .03 gms silicone	25min., CM	190	X CP		
	12.5 gms to .7 gms and .06 gms silicone	30min.	200	X CP		
	12.5 gms to .5 gms	25min., CM	190			X
Ethyl Silicate and Polyvinyl Butyrol PAT. 3,476,827	12.5 gms to 3.0 gms	30min.	292	X C		
	12.5 gms to 3.0 gms with .03 gms silicone	30min.	292	X		
Glass Resin	100%	16hrs.	200	X		
	100% Reduced Catalyst	5hrs.	200		X	
	100% Reduced Catalyst	16hrs.	200	X		
	100% Added Catalyst	5hrs.	200	X Y		

CM = Compression Molding
CP = Coating Peeled
Y = Yellow
C = Cloudy

Polyvinyl Coatings

Due to its inherent flow characteristics and rapid drying, polyvinyl alcohol was evaluated as a potential lens coating. By itself polyvinyl alcohol is a simple long chain polymer that is water soluble. When a cross-linking agent is added, however, it achieves good coating properties. Quilon, a DuPont chrome complex cross-linking agent was used. The coating is applied after cleaning and cured at 250°F for 15 minutes. After curing, the coating is water insoluble and resistant to most solvents, including acetone. It is close to CR-39 in abrasion resistance. Several drawbacks were encountered: it is not as hard as the O-I coating; it has a blue tint; and it tends to peel. For these reasons, it was considered inadequate for this project.

Mobay Chemical E-397

A new coating, E-397, has been developed by Mobay Chemical which is not yet offered commercially. The resin formulation is unknown, but it has the properties of a urethane or urethane/melamine combination. It is provided as a liquid ready to use. The process is simple and straightforward: cleaning with ethanol, coating, and curing at 270°F. The result is a clear, smooth coating that is resistant to most solvents. It is harder and more abrasion resistant than the O-I coating which in turn is harder and more abrasion resistant than CR-39.

Evaluation Summary

Epoxies, melamines, and epoxymelamines improve the abrasion resistance of polycarbonate, but are no better than CR-39 and in most cases inferior. The siloxanes are much harder than the epoxy/melamines and as a result more abrasion resistant. Non-proprietary formulations of siloxane are as good as CR-39. DuPont Abcite and the Owens-Illinois Glass Resin are about equal and are both superior to CR-39 in abrasion resistance. Due to their licensing requirements, Abcite is prohibitive for this project. Cross-linked polyvinyl alcohol is similar to the epoxymelamines in abrasion resistance, but has other drawbacks. Mobay Chemical E-397 is superior to the siloxanes in abrasion resistance and generally similar in other respects. As the coating procedure is generally the same, the Owens-Illinois Glass Resin and the Mobay E-397 have both been selected and are in use with the laboratory system. Either will provide a superior lens and the simplest to handle from all standpoints will determine the final selection.

TABLE III

Properties of Cured E-397 Coating on MERLON Polycarbonate Substrate

Adhesion of E-397 (Scotch-tape, cross-hatched):

Unaged	Excellent (100%)
Aged 1000 hours, RS sunlamp	Excellent (100%)
Aged 440 hours, 38°C. (100°F.)/100% relative humidity	Excellent (100%)

Optical properties:

	Uncoated		Coated with E-397	
	Unaged	Aged 1000 Hrs., RS Sunlamp	Unaged	Aged 1000 Hrs., RS Sunlamp
Haze, % (ASTM D 1003)	3.4	5.1	2.7	3.0
Luminous transmittance, % (ASTM D 1003)	83.6	82.9	86.8	85.9
Reflectance at 420 nm, % (Vitrolite, ASTM E 308)	67.1	52.5	69.5	68.0

Abrasion resistance:	Uncoated	Coated
Increase in haze, %, Taber abraser, CS-10F wheel, 500 grams, 100 revolutions (ASA Z26-1--5.17)	20	<5
Increase in haze, %, falling sand	10.9	2.8

Solvent resistance:

E-397 improves the resistance of the MERLON substrate to such solvents as toluene, gasoline, carbon tetrachloride, acetone and methyl ethyl ketone.

Weathering:

Accelerated laboratory and outdoor aging tests have demonstrated the ability of E-397 coating, when properly applied, to provide a polycarbonate with greatly improved retention of color and gloss characteristics. E-397 does not lose adhesion, clarity nor scratch resistance after such agings.

COATING PROCESS

The development of a coating process has paralleled the evaluation of coating materials, and varies slightly with the material, especially as to primers and solvents. The overall process is basically the same in all cases. The lenses are cleared, coated, and then cured.

Preparation of solutions and handling and storage is a highly critical aspect of the coating process. At these stages it is possible to contaminate the solutions with particulate material which will appear on the lens in the coating. The prevention of contamination during preparation, handling, and storage, is practically impossible. Therefore all solutions are filtered just prior to use with a pressure filter system capable of removing particles 5 microns or larger.

Fixtures for holding the lens during the process have been developed so that it may be held securely, but not block any portion of the lens surface and prevent the coating material from adhering to a small portion. The points of contact are minimal as they can be a source of streaming of the coating material with an unequal distribution of coating and a distortion of the optical characteristics. The points of contact are on the lens edge where distortion or lack of coating have no effect on lens quality, as the lens will be edged to size before mounting in frames.

DESIGN ANALYSES

MOLDS

In the last technical report it was indicated that beryllium-copper with chrome plating provided the best mold material to that time evaluated. In constant use, the chrome plating began to pit and, subsequently, to break down, thus giving a short mold life. A number of attempts to remedy this were made. The results were marginal. The thermal conductivity of chrome coupled with its particular plating characteristics caused the chrome to creep over the beryllium surface and break down.

Another approach was taken. Nickel was plated onto the beryllium-copper mold, then finish surfaced. A moderate improvement was noted. The next step was to temper the molds. A series of trials occurred here. This finally produced molds of excellent optical and wear characteristics.

The mold design now is completed, molds are made from beryllium-copper and smooth cut to sphere, cylinder, and spherocylinder. They are then nickel-plated and finish surfaced. Then they are tempered at 700°F and rechecked. These molds are now being fabricated y Tinsley Laboratories to LSRI specifications. Molds thus produced have been in use for some time, have excellent wear characteristics, as well as producing excellent lenses.

COMPUTER SELECTION

Evaluation of the computer for the final pre-prototype/breadboard system was completed during this period. Selection was narrowed to three systems: Hewlett-Packard 9100; Olivetti P602, and Wang 700. All three have provisions for electro-mechanical interface and paper print-out.

The Wang 700 Computer was finally selected as first choice. It has good potential for the final pre-prototype/breadboard system. It is rugged and reliable. It has plug-in circuit boards which can be replaced using a simple troubleshooting schema. The keyboard can be adapted to the breadboard system allowing a straightforward entry of prescription information.

ASLFS OPERATIONAL CONCEPT

An analysis of the overall Automatic Spectacle Lens Fabrication System (ASLFS) conceptual design provides a description of the ASLFS operational concept and operational sequence. A schematic of the ASLFS is depicted in Figure 1. The control subsystem consists of the computer with a keyboard and its interface electronic equipment. The control subsystem drives the electromechanical components. The computer is also programmed with all the prescription information necessary to allow the proper lens to be molded. The computer also controls the coating and edging units.

The electromechanical subsystem consists of several components or units. A plastic material unit provides storage for the polycarbonate and constant dehumidification. This unit also includes the mechanism for volumetric measurement of the individual charge and transfer to the molding unit. Heating and cooling units provide the necessary thermal transfer to the mold assembly, and the mold assembly is driven by a servo unit. The coating and edging units are part of the electromechanical subsystem; and, although they are activated by the control subsystem, they are independent of the molding unit. The entire system is powered by the power subsystem which is an off-the-shelf power unit.

The ASLFS operational sequence is outlined in Table IV. This table is vertically divided to indicate operator functions and machine functions. It is horizontally divided to separate start-up and shut-down functions from operational functions. The start-up sequence is accomplished daily or when the ASLFS is moved to a new location. The operator's task is mainly concerned with filling the resin reservoirs and then turning on the ASLFS. This in turn activates all the subsystems.

During operations, the operator enters the prescription via the keyboard which starts the molding sequence. The computer then controls the total molding cycle. After the molded lens is ejected, the operator removes the lens and mounts it simply in the edger already programmed for the edging operation. After the lens is edged, the operator removes it and mounts it in the coating unit. The coated and cured lens pair is removed and simply mounted in the adjustable frame by use of a template-type mounting device. The shutdown cycle provides for securing the ASLFS for transportation.

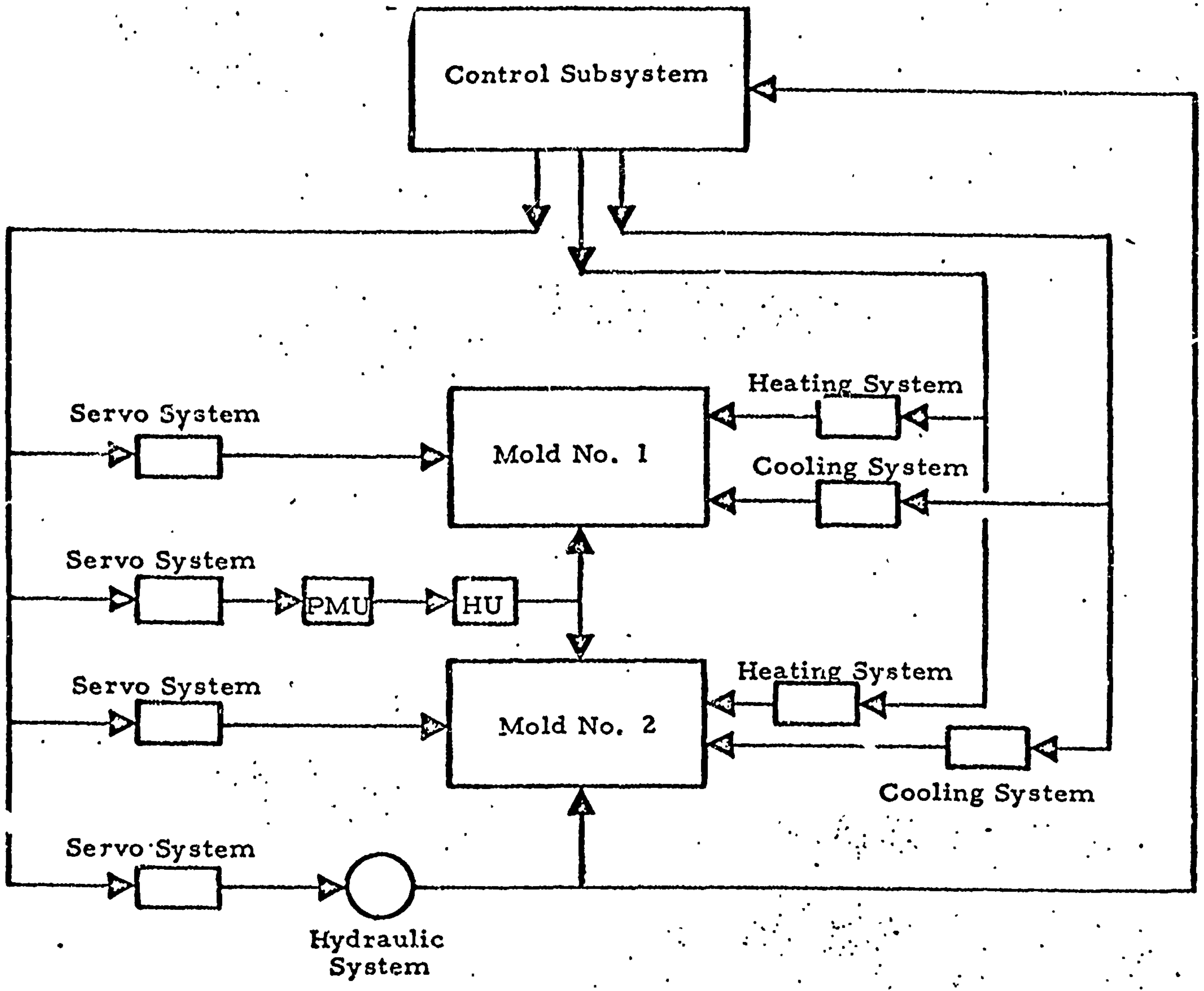

Figure 1. Schematic of the ASLFS Pre-Prototype/Breadboard Model

TABLE IV

ASLFS SEQUENCE

OPERATOR	MACHINE
START-UP 1. LOAD FILL POLYCARBONATE HOPPER FILL COATING TANKS 2. SWITCH-ON	1. POWER ON, COMPUTER ON, COOLANT AND HEATER SYSTEMS ON 2. POLYCARBONATE DRYING AND CURING CHAMBER HEATING COMMENCED
OPERATIONS 1. ENTER PRESCRIPTION R&L S, Cx AXIS, P.D. 2. LENS REMOVED AND MOUNTED IN EDGER 3. LENS REMOVED AND PLACED IN COATER 4. LENS REMOVED AND MOUNTED IN FRAME AT CORRECT P.D., PADS AND TEMPLES ADJUSTED	1. COMPUTER ACTIVATED AND PREPROGRAMMED CYCLE 2. MOLDS INDEXED AND ALIGNED, MOLDS AIR CLEANED 3. EDGER INDEXED 4. SHOT MEASURED VOLUMETRICALLY, TRANSFERRED, LOADED INTO LOWER MOLD CAVITY 5. MOLDING ACCOMPLISHED 6. LENS EJECTED 7. LENS EDGED 8. LENS AIR CLEANED, WASHED, RINSED, DRIED, COATED, AND CURED
SHUT-DOWN 1. SWITCH-OFF 2. FILTER OR MIX NEW COATING AS REQUIRED 3. CLOSE HOPPER AND TANKS WITH POSITIVE CLOSURES 4. SECURE FOR TRANSPORT IF REQUIRED	1. POWER OFF, ALL SYSTEMS OFF

PRELIMINARY DESIGN

Based upon the design analyses, breadboard studies, and conceptual design, a preliminary design was commenced. The most difficult areas are being approached first; these are: the molding unit; the volumetric measuring portion of the plastic materials unit, and the coating unit. Preliminary design was initially directed toward the molding unit. This effort is summarized here through a series of figures.

An overall side view of the molding unit is depicted in Figure 2 and an overall top view in Figure 3. The molds are mounted in two rigid discs — plus molds on one and the minus molds on the other. The mounting is such that the molds can travel in a vertical direction during the molding cycle. When the prescription is keyed, the appropriate molds are indexed to the mold assembly position.

Close-up views of the single mold assembly are shown in Figure 4 and Figure 5. When the proper molds are indexed to the mold assembly, the molds are cleaned, the mold assembly closes, and the lower mold is positioned. The charge is then loaded and the upper mold positioned and the heating cycle commences.

Although the figure shows only one mold assembly, two are planned to provide a back-up or redundant mold assembly.

The final figures depict the actual mold drawings to be used for fabrication. Figure 6 for convex molds, and Figure 7 for concave molds.

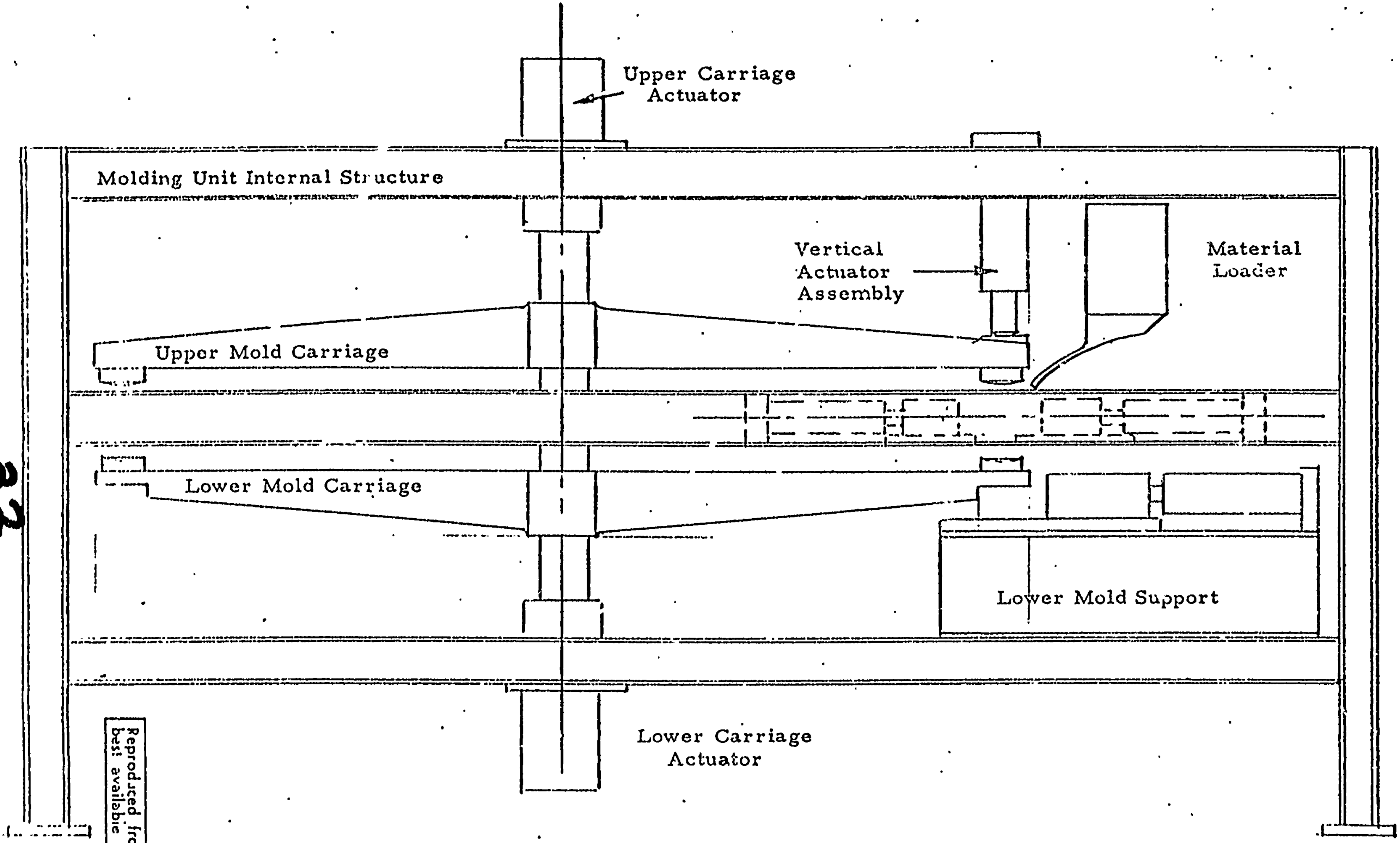

Figure 2. Overall Side View of Molding Unit

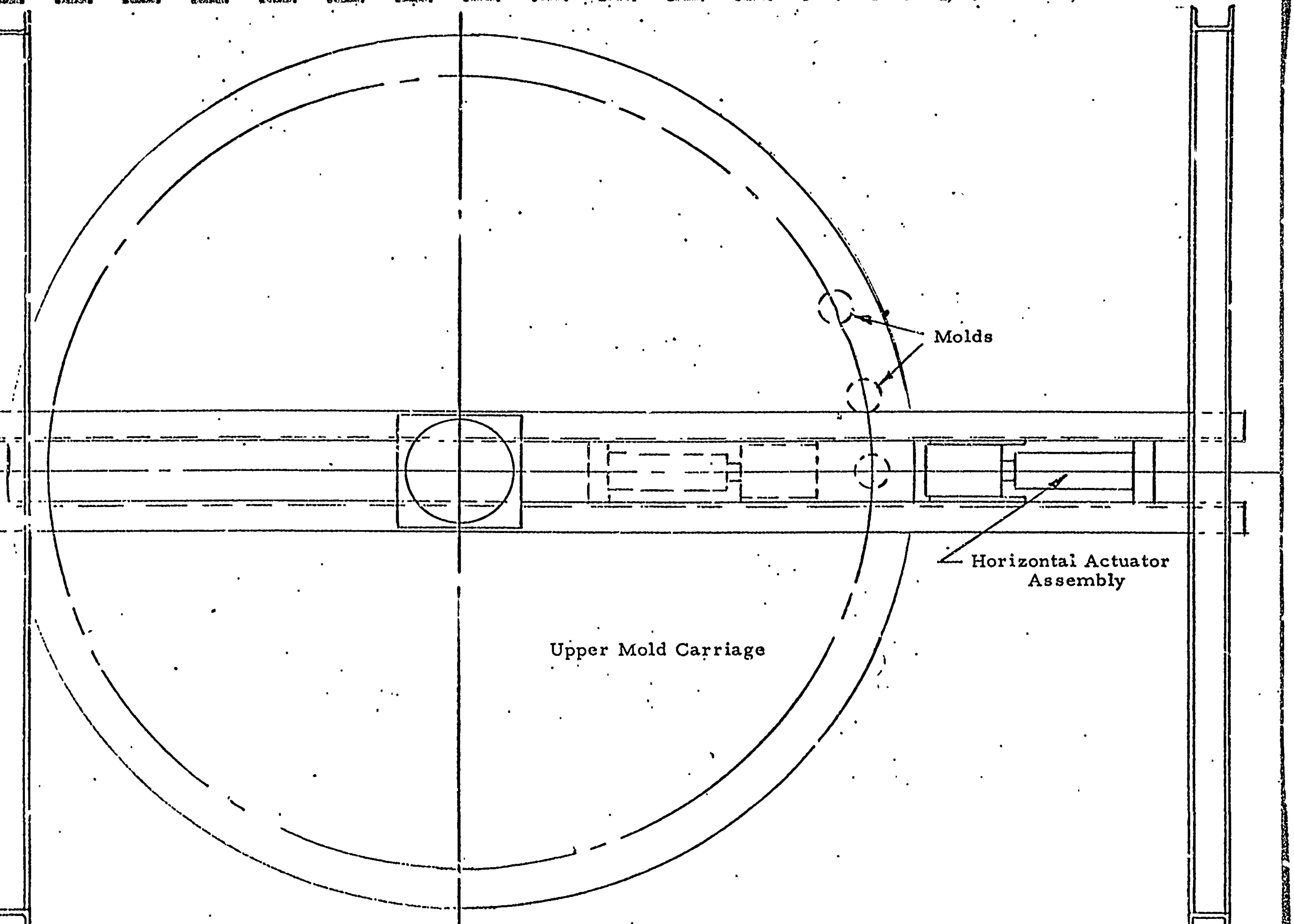

Figure 3. Overall Top View of Molding Unit

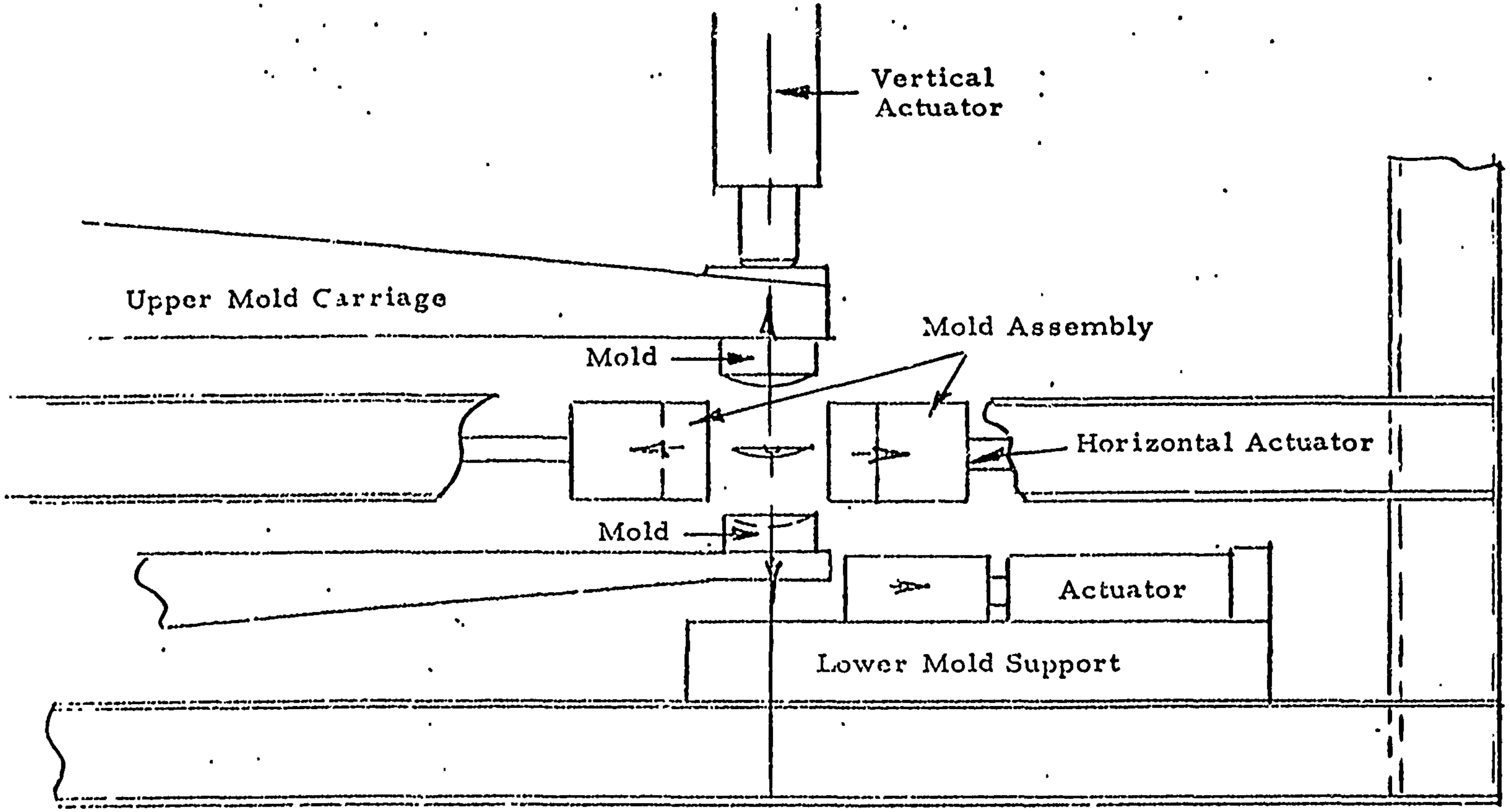

Figure 4. Side View of Mold Assembly - Open

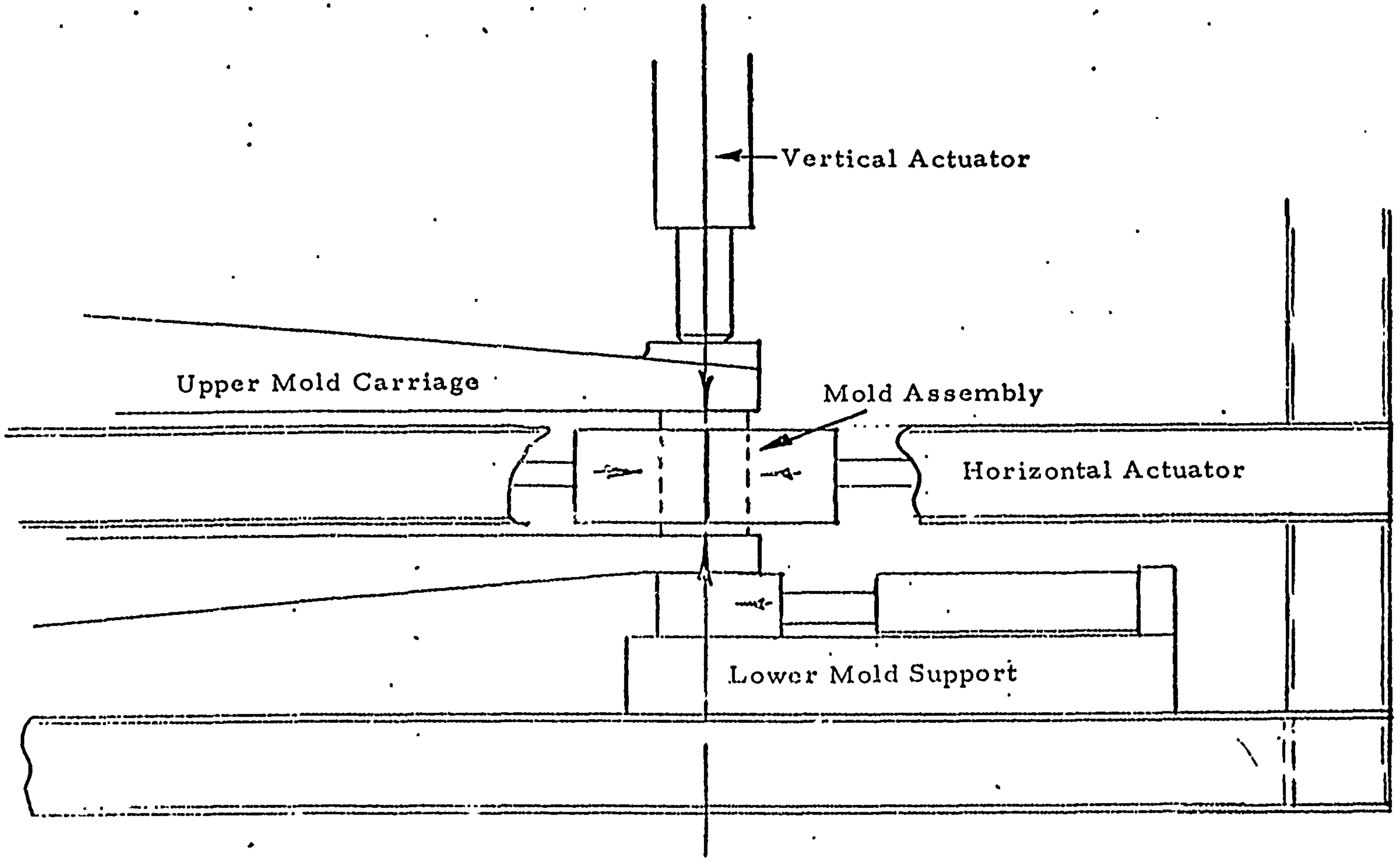

Figure 5. Side View of Mold Assembly - Closed

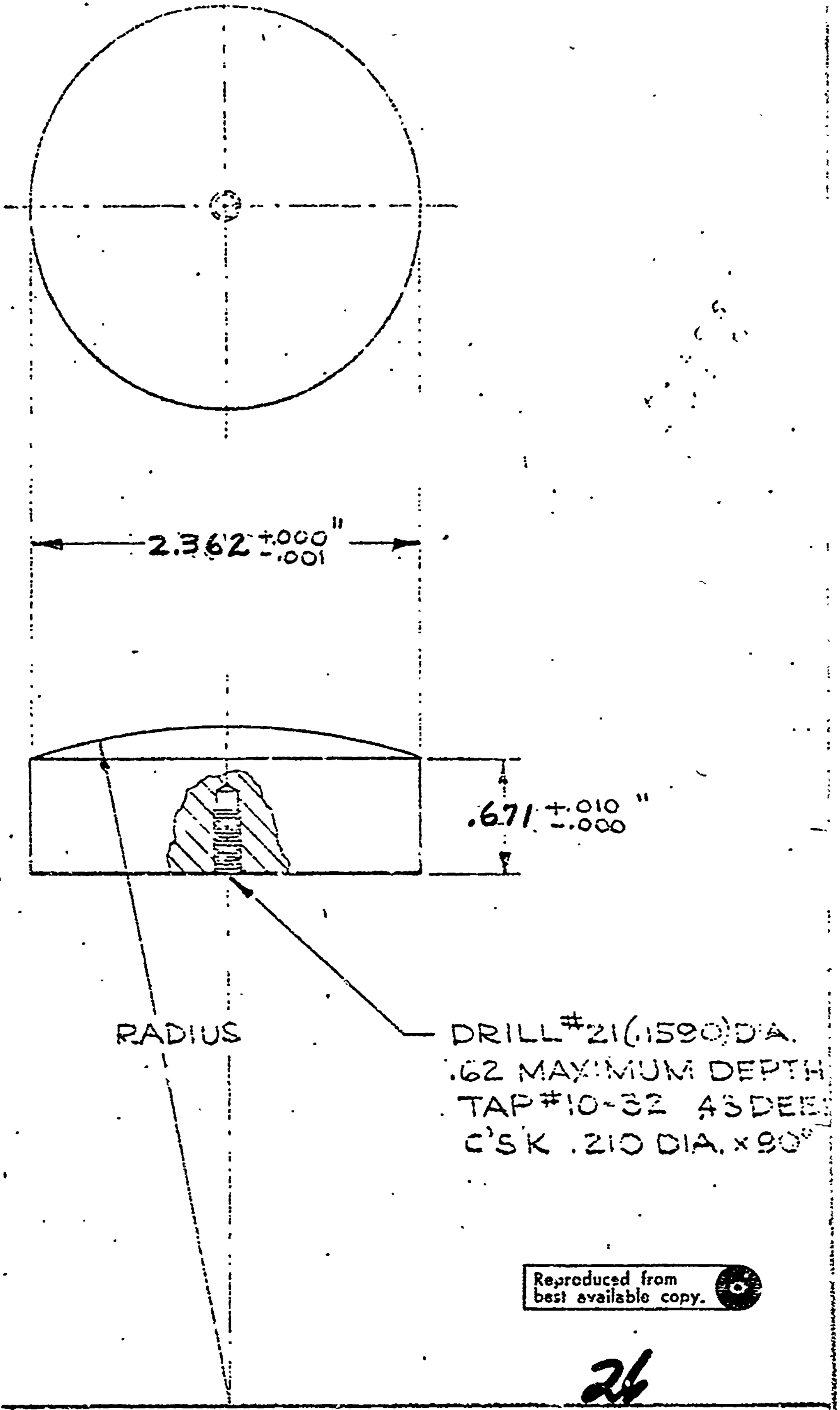

Figure 6.

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SCALE FULL	MATERIAL BERYLLIUM COPPER	DRAWN BY N. Ivan	DATE 7JAN72	APPROVED BY	DATE
TITLE LENS MOLD(DIE)-CONVEX				DRAWING NO. C 1013	REVISION

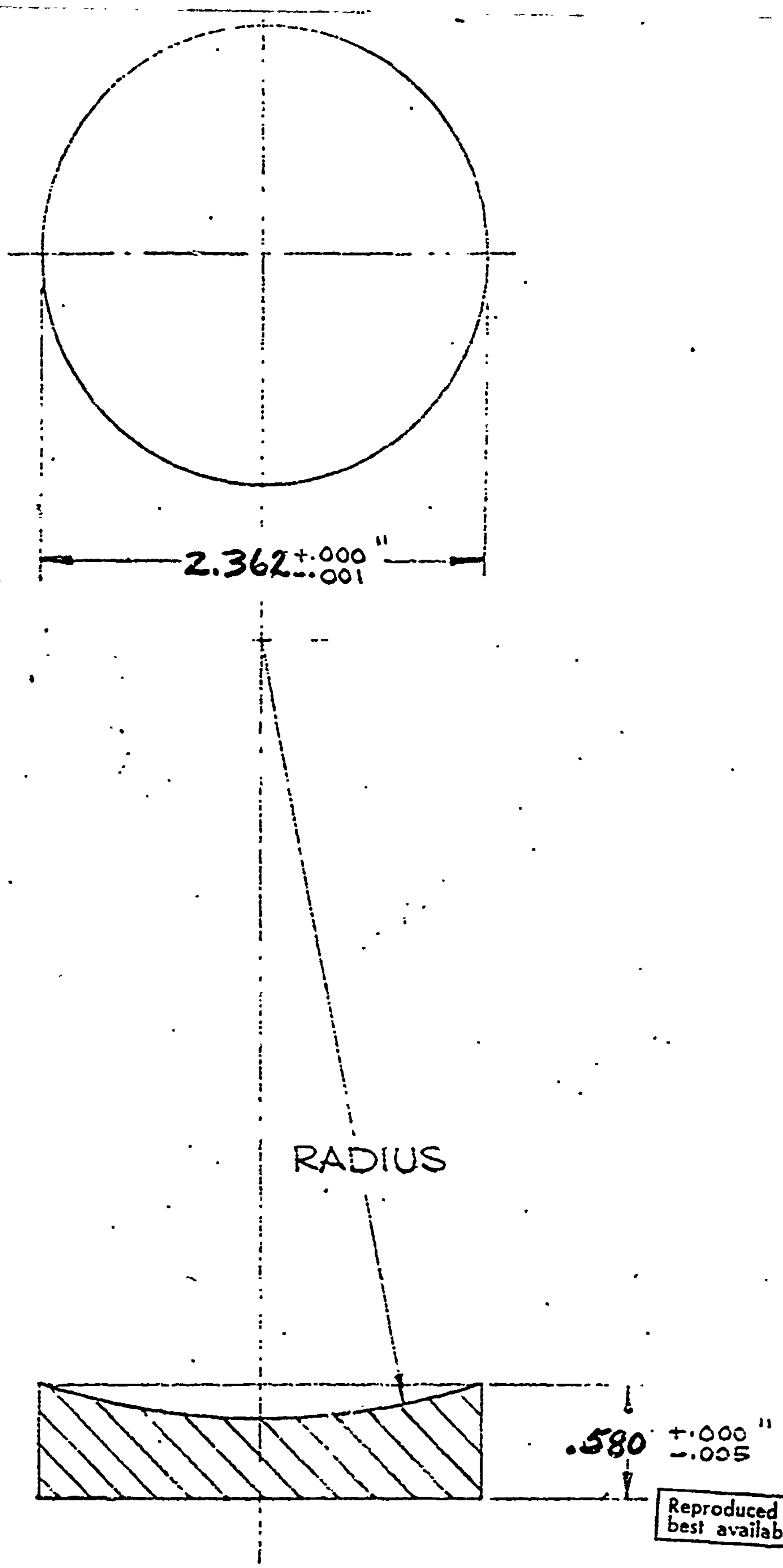

Figure 7.

LIFE SYSTEMS RESEARCH INSTITUTE					
SCALE FULL	MATERIAL BERYLLIUM COPPER	DRAWN BY	DATE 10JAN72	APPROVED BY [illegible]	DATE [illegible]
TITLE LENS MOLD (DIE) - CONCAVE C				DRAWING NO. 1014	REVISION