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TECHNICAL REPORT NO. LWL-CR-50P71

ABRASION RESISTANT LENS CAPS

Final Report
Contract No. DAAD05-68-C-0283

By
Franklin Institute Research Laboratories
Benjamin Franklin Parkway
Philadelphia, Pennsylvania

October 1971

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ABSTRACT

Various materials were tested for their suitability as abrasion resistant lens caps for binoculars as were the binocular lenses themselves. It was determined that artificial sapphire was the best material tested but because of high cost it was not considered suitable for protecting the objective lenses of ordinary binoculars. Optical glasses exhibit good properties and would be suitable lens cap materials. It was also determined that abrasion on the eyepiece lens or lens cap degrades the overall optical quality greater than a comparable degradation of the objective lens or lens cap. The polycarbonate and plexiglass materials were found to be very susceptible to abrasion and are considered to be unacceptable for lens caps.

1.0 INTRODUCTION

The use of binoculars and other optical devices in a sand or dust laden environment may cause severe degradation of the lenses. It, therefore, may be desirable to have "see through" lens caps which are capable of withstanding the abrading effects of the sandy environment.

The particular objectives of this work assignment are to evaluate the effects of an abrasive, sandy environment on the coated lenses found in the M-17 binoculars; on the same lenses with the coating removed; and on various materials whose characteristics lend themselves to use as "see through" lens caps for the M-17 binoculars. In addition, it was required that the optical coatings be removed from the objective and eyepiece lenses of the M-17 binoculars and adapters be designed to facilitate the mounting of the "see through" lens caps to the M-17 binoculars so that further operational tests could be performed by the U.S.A. Land Warfare Laboratory.

2.0 CONCLUSIONS AND RECOMMENDATIONS

(1) The test results summarized in Table I and Figure 8 indicate the following percentage degradation in the materials subjected to 6 minutes of dust chamber abrasion.

<u>Material</u>	<u>Per Cent Degradation</u>
Sapphire	0%
Slide Glass	11%
Optical Glass	25%
Quartz	39%
Thin Tygon	40% *
Plexiglass	49%
Polycarbonate	100%

The lenses^{**} themselves when subjected to 6 minutes of dust chamber abrasion indicated the following percentage degradation:

<u>Lens</u>	<u>Per Cent Degradation</u>
Coated	52%
Uncoated	100%

* The thin Tygon, though the test data indicates a relatively good resistance to abrasion, has such poor optical qualities it cannot be considered for use. If it could be produced with better optical qualities such as homogeneity and surface flatness, it might well be a material worth considering.

** The abrasion test was the same as other materials, but the measurement procedure was different for lenses.

From these data it can be concluded that a "see through" lens cap of suitable material is more abrasion resistant than the coated lenses themselves. However, further operational tests are required to determine if these materials in fact would improve the optical system performance in an abrasive environment when other factors such as reflection, distortion, color aberrations and light gathering power are considered.

(2) As a result of the tests performed, the following materials were selected for use as windows in the dust covers to be supplied:

- (a) Sapphire
- (b) Slide Glass
- (c) Optical Glass
- (d) Quartz
- (e) Polycarbonate

It is estimated that the materials will be ranked in the order listed by the Sand and Dust Tests (MIL-STD-810B; Method 510) to be performed by the Government.

(3) The failure of Polycarbonate to meet the anticipated performance implied by its high impact resistance is due to an apparent difference between the materials resistance to gross fracture under impact and its resistance to surface erosion caused by small high speed particles. The same is true for the other viscoelastic polymer materials tested.

A coating for polycarbonate is available (through the Sieracin Corporation and the Goodyear Aerospace Corporation) that increases its resistance to marring and scratching. This coating is being evaluated by the Government for use on polycarbonate visor lenses for the HGU-2A/P helmet (Project No. TAC 70A-156T/TAWC 0085). This coating may also increase its resistance to abrasion in a dust and sand laden environment. No tests were made of coated polycarbonate. However, it is not expected that it will be better than the other materials selected.

(4) It appears that abrasive degradation of the eyepiece dust window will have a greater effect on the performance of the binoculars than degradation of the objective dust window. Consequently sample eyepiece dust covers were supplied with sapphire windows. These windows are quite expensive but their excellent performance may be worth the cost to provide the added protection for the more critical eyepiece lens.

(5) The sapphire showed no apparent degradation, even after 12 minutes in the abrasive environment of the dust chamber. Its basic optical properties are not quite as good as other materials tested and it is quite expensive. It is, however, available with better optical qualities at increased cost. The cost prohibits its use on binoculars, since the caps would cost more than the binoculars themselves. However, the sapphire begins to look very attractive when considered as a lens cover on such sophisticated and expensive optical systems such as telescopes, range finders and laser communicators.

(6) Recent developmental research activities with transparent ceramics being made into lenses (see Industrial Research, May, 1971, p. 40), indicate it may become economically feasible to consider using these materials for the lenses of binoculars (and other optical devices) that are exposed to abrasive environments. It is recommended that USALWL pay close attention to this area of research and even consider supporting some efforts on its own.

(7) Until further operational tests are performed--see item (1) above--no recommendations can be made regarding the use of "see through" lens caps. Obviously some unknown amount of degradation will be added to the optical system due to the attenuation, reflection and distortion of the "see through" lens caps. However, this degradation may be tolerable in the abrasive environment in which the lens caps would be used.

3.0 TEST AND EVALUATION

3.1 "See Through Window" Material Selection

The work assignment required that four materials be selected for further testing. Two were specified, namely, polycarbonate and glass. Two additional materials were to be selected on the basis of laboratory tests. The following paragraphs discuss the characteristics of the materials considered:

(1) Polycarbonate: There are at least two commercially available materials in this category. Lexan produced by General Electric in Pittsfield, Mass., and Merlon produced by Mobay Chemical. A third, Noryl, a modified polyphenylene oxide, is very similar to these. Because of their very similar characteristics, only one was selected for test, Lexan. It has a hardness of R115 on the Rockwell scale.

(2) Optical Glass: There are numerous possible types of optical glass to select. A sample of Quality Float Glass manufactured by Liberty Mirror, a division of Libbey-Owens-Ford Co., was selected. This material was selected because of its excellent optical quality and its high impact resistance. This glass is used in the manufacture of shatter-proof automobile windshields; it has an estimated hardness of 5.0 on the Moh's scale and a hardness of 136 Kg/mm^2 on the Knoop scale.

(3) Fused Quartz: This material is known for its fine optical quality and hardness. Samples of optical grade A-1 were obtained from the Thermal American Fused Quartz Co., Montville, N. J. The material has a hardness of 4.9 on the Moh's scale and a hardness of 262 Kg/mm² on the Knoop scale.

(4) Slide Glass: This material is known for its fine optical quality, hardness, and corrosion resistance being used for microscope slides. The material has an estimated hardness of 5.3 on the Moh's scale and a hardness of 314 Kg/mm² on the Knoop scale. The glass is manufactured by the Hausser Company and is available through the Arthur H. Thomas Co., Philadelphia.

(5) Sapphire: Over the past decade, the use of synthetic sapphire has become popular as an optical material because of its excellent transmissivity and its unusual physical properties. Synthetic sapphires have a hardness of 9 on the Moh's scale and a hardness* of 1600-2200 Kg/mm² on the Knoop scale. Samples were obtained from the Union Carbide Crystal Product Division, Union, N.J. Cost is an important factor for this material. One window for the eyepiece is about \$11.50 and for the objective lens, \$150.00. This is for commercial grade optical polishing. Better optical quality is available at increased cost.

(6) Tygon: This material was selected for its toughness and resilience. It was felt that the surface of a material of this type might not deteriorate as rapidly as a hard surface in a sand and dust environment. Samples of two thicknesses (1/32" and 3/32") of Press-Polished sheeting of Formulation B44-3 (clearest possible) were obtained from Norton Plastics Co., Akron, Ohio.

(7) Poly(methyl-methacrylate): This material is manufactured by the Rohm and Haas Company, Philadelphia, under the trade-name Plexiglass. It has good optical characteristics and a hardness of M-93 on the Rockwell scale which is roughly equivalent of 2.5 on the Moh's scale.

* Manufacturer's published value.

(8) Polyvinylidene Chloride: This material is commercially available under the trade-name Saran Wrap. This material was tested in two applications: (1) a thin film over a glass backing, and (2) a taut thin film with no backing.

3.2 Materials Considered and Not Tested

In addition to the above materials, the following were considered for testing but excluded for the reasons listed:

(1) Calobar: A clear super armor plate lens material produced by the American Optical Co., Philadelphia. This material was not included because it is not available in stock thin enough for this application.

(2) Borosilicate Glass: This material, produced by General Electric, is used in a wide variety of high temperature applications. However, it was not included because it is rather soft and scratches easily.

(3) Transparent Ceramics: There are several of these materials that exhibit hardness from 6.0 to 7.2 on the Moh's scale which is second only to sapphire of the materials considered. These materials are in the developmental stage under guidance of the Air Force Materials Laboratory, Wright Patterson AFB, Dayton. One material, transparent MgO, has a density of 3.5 g/cm^3 and a hardness of about 6 on the Moh's scale. Another material of comparable characteristics is Irtran 2, produced by Kodak. A third material, Yttralox, produced by General Electric, has a density of 5.3 g/cm^3 and a hardness of 7.2 on the Moh's scale. Another similar material is Lucalox. In addition, developmental research is being conducted with ZnS powder and with CdS.

These materials are presently more expensive than sapphire and usually have less favorable optical properties, thus they were excluded. However, as improved materials are developed and costs are reduced, it may become feasible to consider these materials in the future.

(4) Viscoelastic Polymers: Several varieties of these materials were considered but not included in the test because there was no reason to believe their performance would exceed that of Lexan or Tygon. These consisted of Polyvinylchloride, Polyurethane, and CR39.

3.3 Material and Lens Testing

It was necessary to determine the relative quality of the various materials when they were subjected to identical conditions of abrasion. To accomplish this a special dust chamber was designed and fabricated to abrade the candidate materials. The relative optical quality of each sample was then measured to obtain a figure of merit for the material.

3.3.1 Dust Chamber

In an effort to approximate the conditions of the Sand and Dust Test (MIL-STD-810 B; Method 510), a dust chamber was designed and fabricated for exposing candidate window materials to blowing sand and dust particles. (See figures 1 through 3) The chamber consisted of an enclosure, a sand blasting gun, a sand container with feeder hose, a regulated compressed air source, an air filter, and an exhaust vented hood. The test dust was 140-mesh silica flour as required by the above mentioned specification. Air pressure was adjusted to 5 psi and pulsed in order to assure continued and even flow of dust.

Under these conditions, a gradual degradation of the surface quality of the various materials was generated. A figure of merit for each material was obtained by measuring the degradation of the optical quality of the material with respect to time.

It should be emphasized that this set up is not intended to reproduce the test environment outlined in the above referenced specification, but only to approximate the results that might be expected. Each candidate material was subjected to 12 minutes of blowing sand and dust. Measurements of optical characteristics were made at selected time intervals for comparison with other materials.

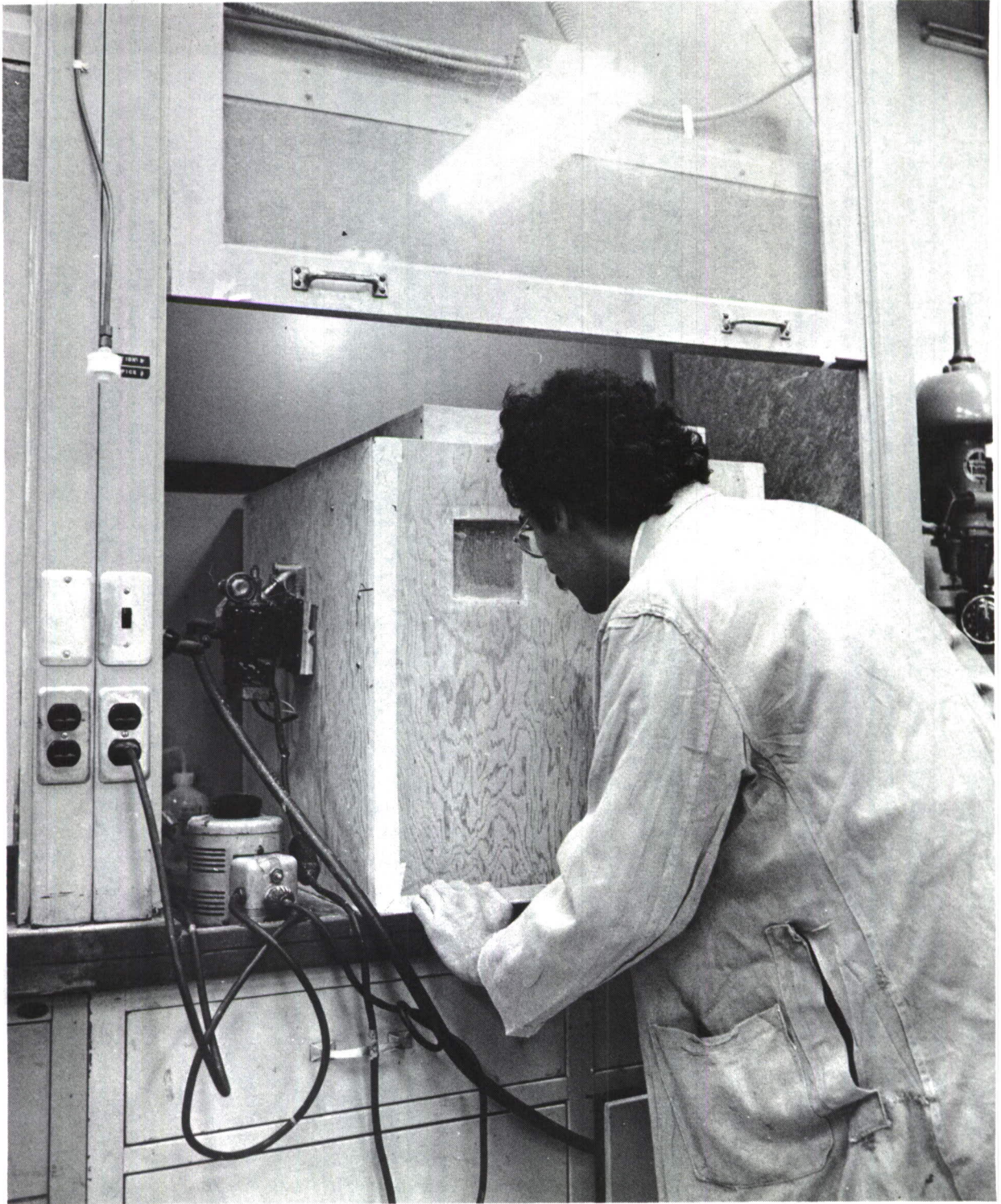


Figure 1 - Overall View of Dust Chamber

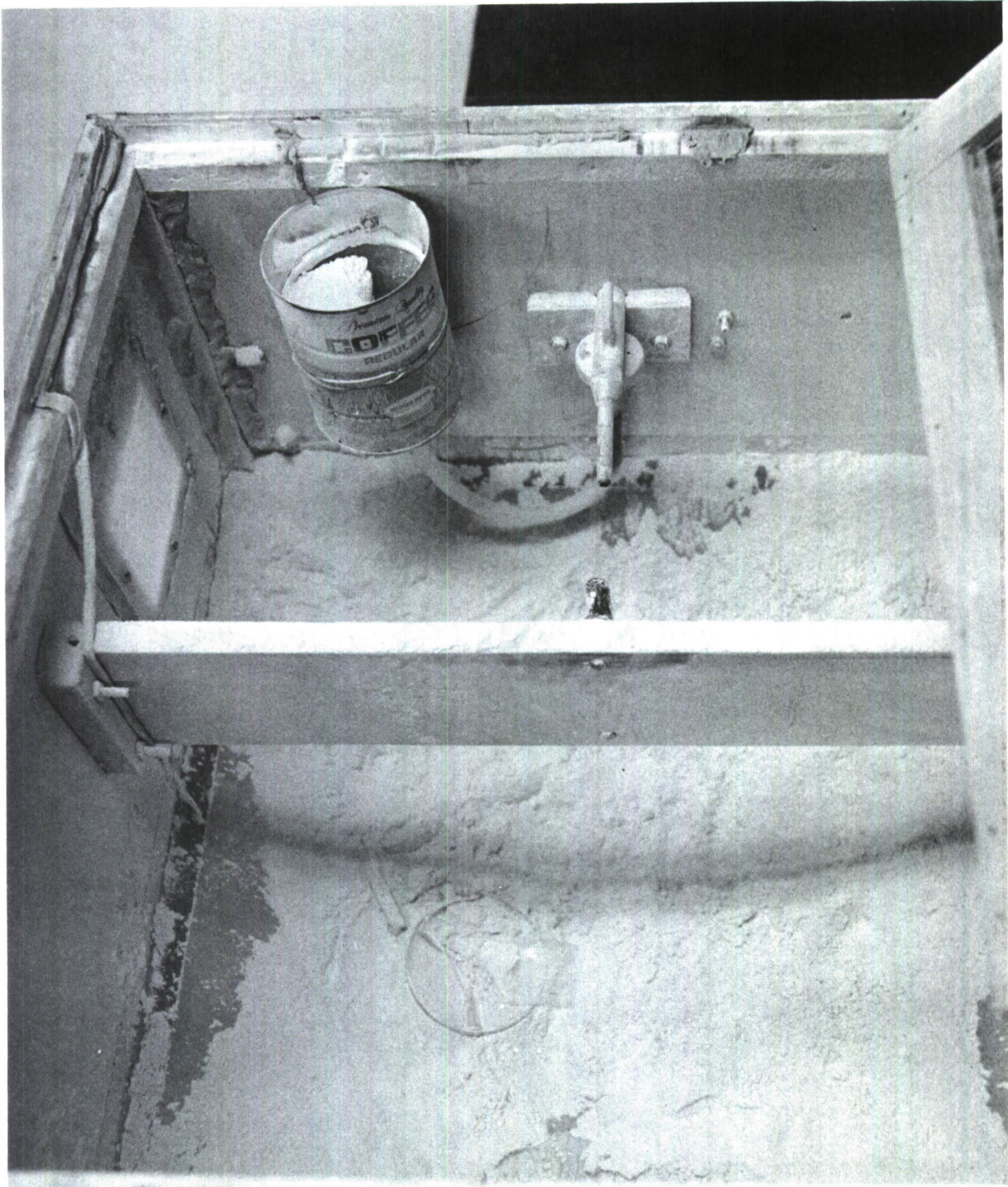


Figure 2 - Interior of Dust Chamber Showing Sand Blasting Gun, Sand Container and Sample Holder.

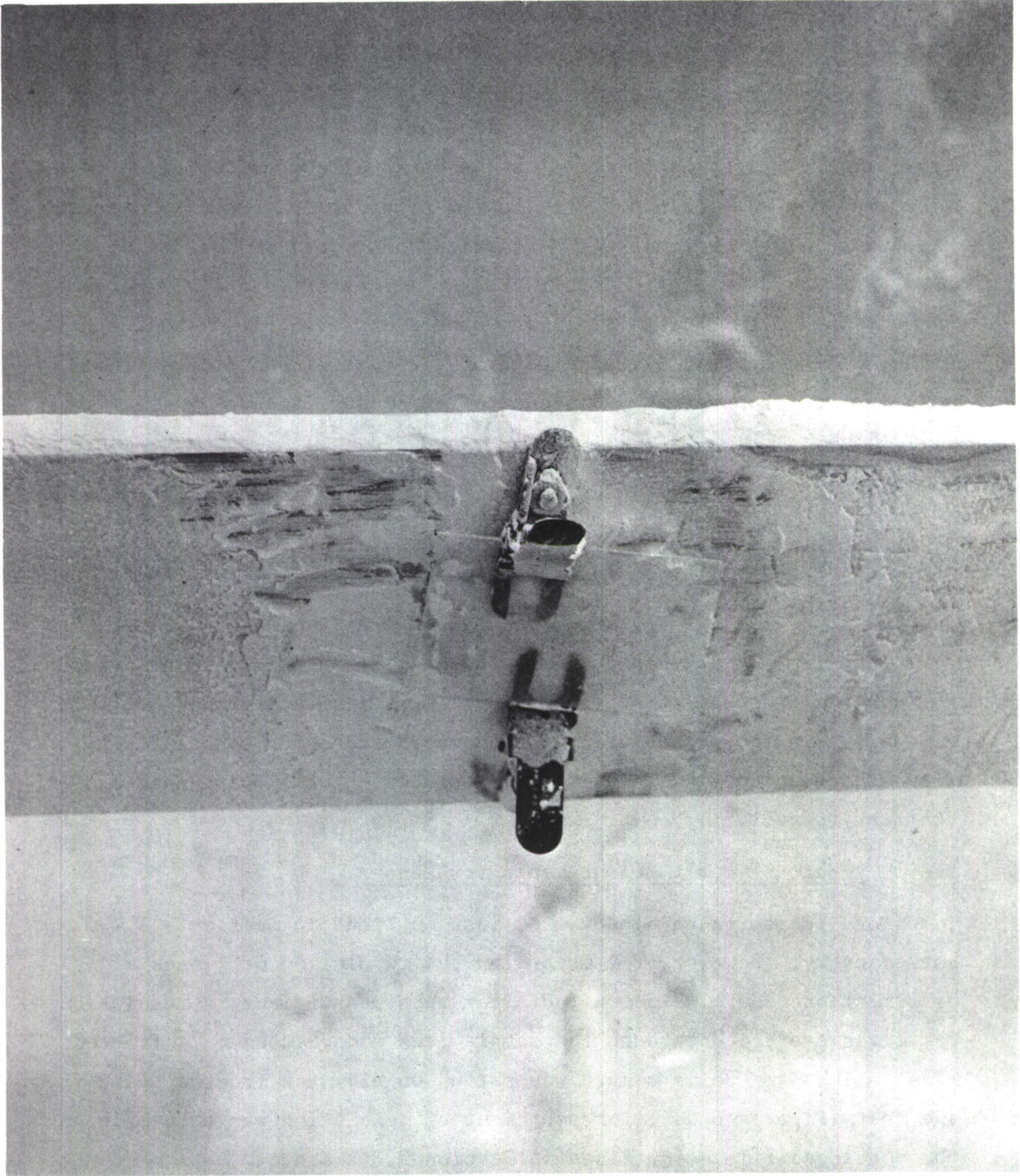


Figure 3 - Close Up of Sample in Place in Chamber.

3.3.2 Figure of Merit Measurements for Window Materials

Various parameters of optical quality are affected by the abrasion of the window surface. In addition to a loss of resolution, there is a loss of contrast and an increase in scatter. However, the measurement of resolution was selected as the basis of comparison of the candidate window materials. The following procedure was used to measure resolution of the materials. A Praktica 35 mm. camera was set up to view a standard resolution chart from 40 inches (Figure 4). The camera was equipped with Plus-X film and operated at f 5.6, 1/500 sec. shutter speed. The chart was illuminated from the rear with a 300 watt lamp adjusted to 1/2 power at a distance of 10 inches (Figure 5).

A mask with .75 X .75 in. opening was placed over the lens of the camera, and the sample window material was placed in front of the camera lens so that the most degraded portion filled the opening of the mask. A photograph was taken of the resolution chart as seen through the degraded window.

The film was developed in Microdol-X 1:1, and the film was viewed through a microscope to determine the lowest resolution scale visible on the film. These resolution data were recorded for each material for each selected time interval of exposure to the blowing sand and dust environment.

3.3.3 Figure of Merit Measurements for Lenses

For flat surfaced windows the test outlined in Section 3.3.2 was satisfactory. However, for measuring the resolution of lenses a different procedure was required. For this measurement, a resolution chart was projected through the sample lens and focused on a frosted glass. The same 35 mm camera was set up to view the frosted glass from the rear (Figures 6 & 7). Measurement of resolution was then made on the developed film as outlined in Section 3.3.2 above.

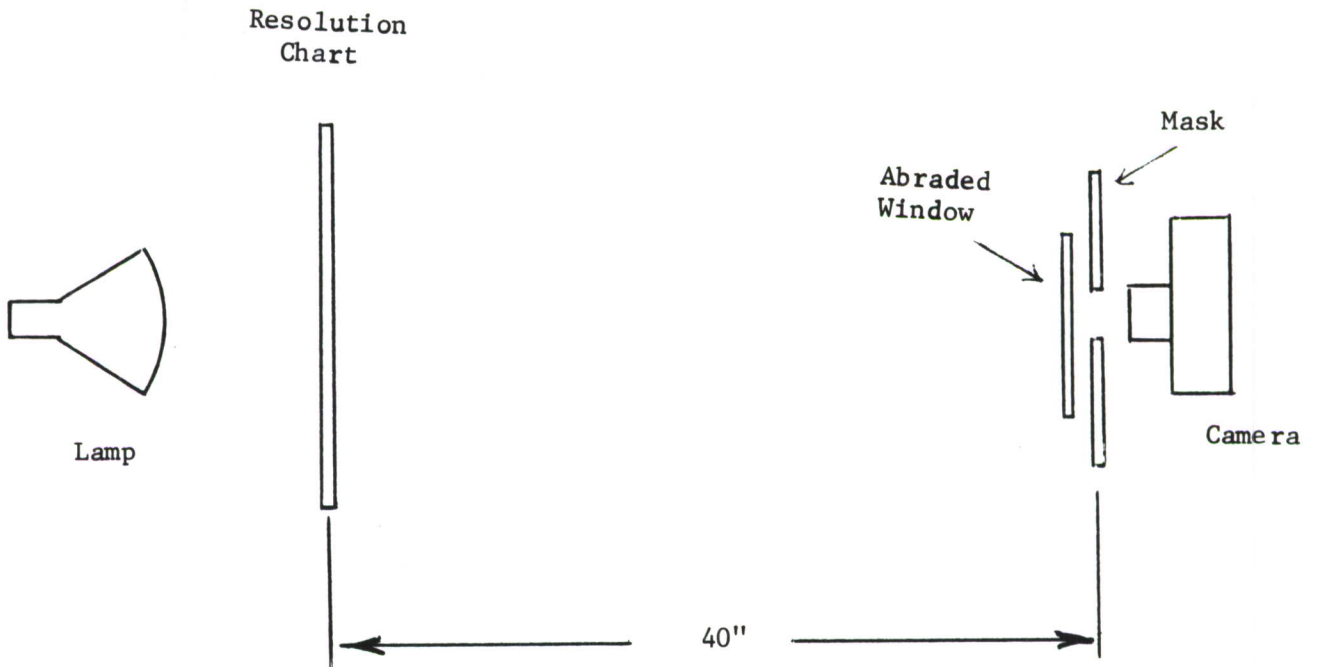


Figure 4 - Schematic Representation of Test Setup for Resolution Degradation of "See Through" Materials.

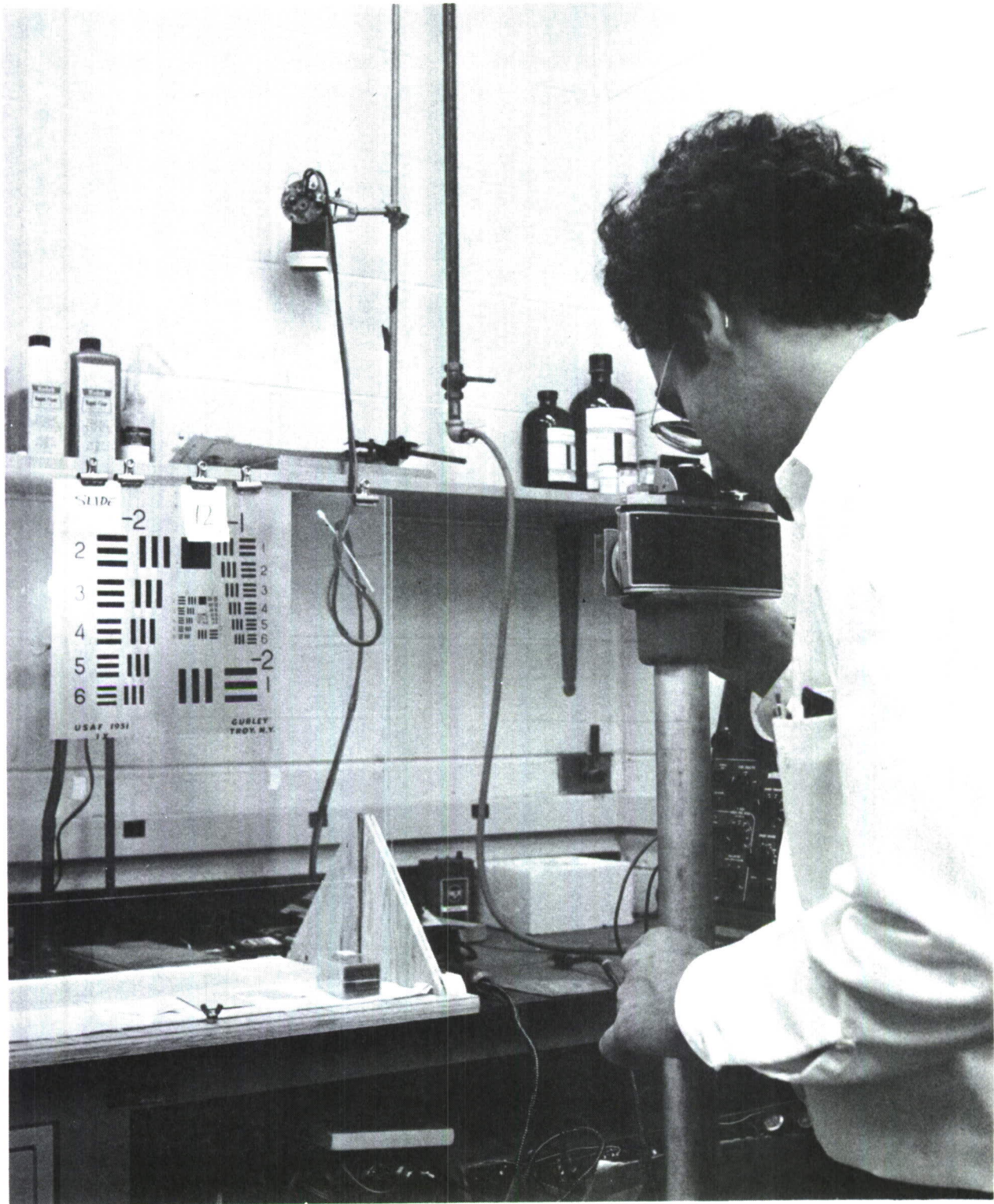


Figure 5 - Test Set Up for Measuring Resolution Degradation of "See Through" Materials.

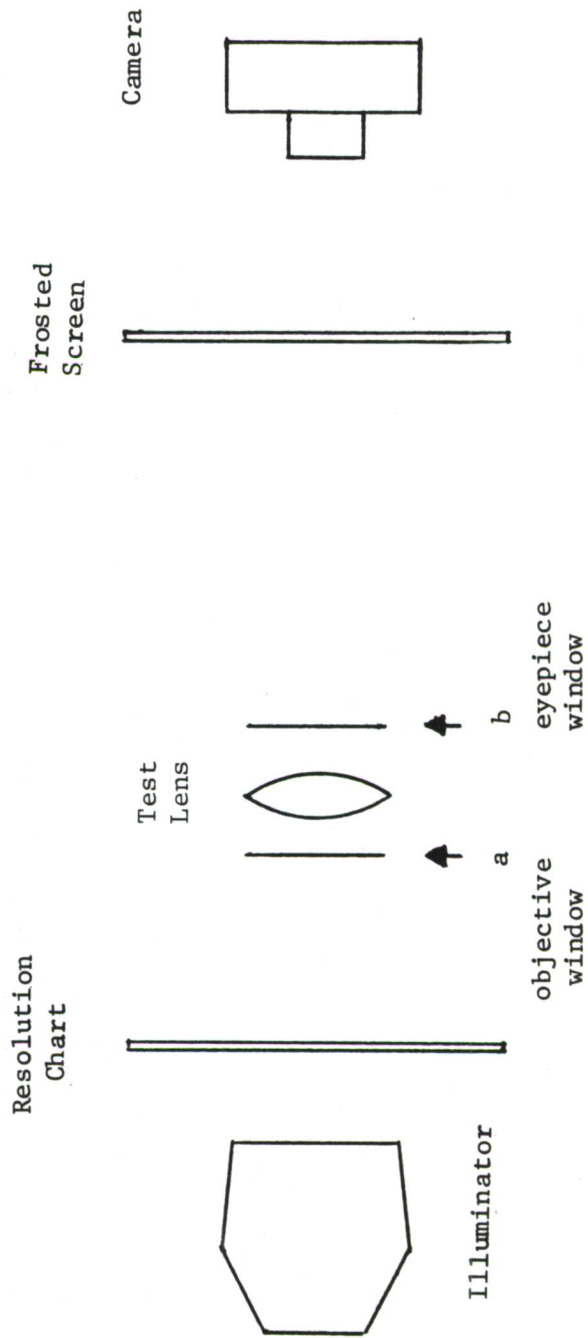


Figure 6 - Schematic Representation of Test Setup for Measuring Lens Degradation.

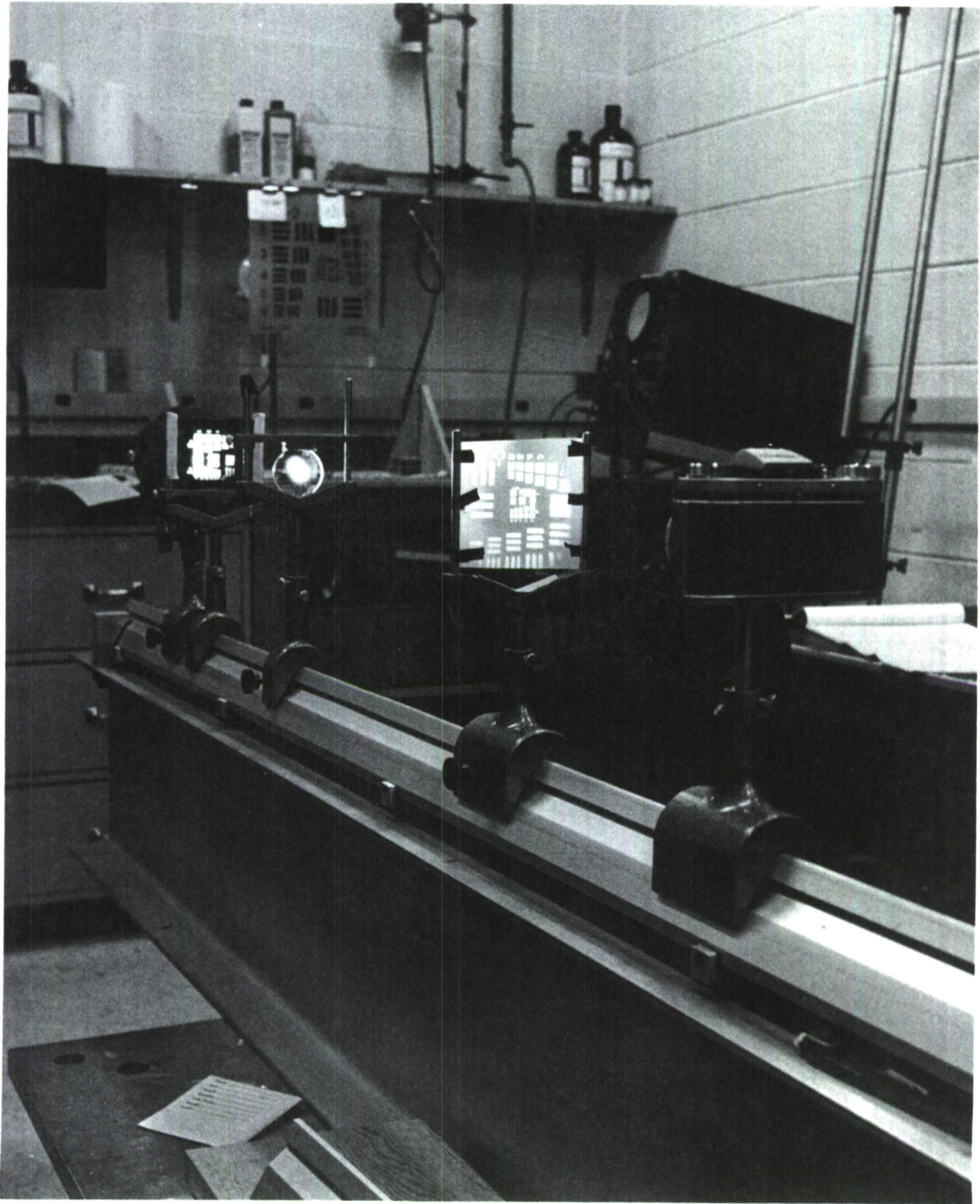


Figure 7 - Test Set Up for Measuring Lens Degradation

3.3.4 Results of Tests Materials

For each of the candidate materials selected for test, resolution measurements were made prior to and after 1, 2, 6, and 12 minutes of sand and dust. Table I is a record of the raw data of the tests. Figure 8a is a graphic representation of results after smoothing (thick Tygon and Saran omitted). Figure 8b shows the same data after normalization. Figures 9 through 15 respectively are prints of the photographic records of the data initially and after 1 and 6 minutes. The prints do not have the same resolution as the original negatives (which were read under a microscope) but they do illustrate the degradation of optical quality, not only in resolution, but also in contrast due to scatter.

3.3.5 Materials Selected for Sample Windows

The work assignment required that lens caps be designed and fabricated from four candidate materials for future Government tests. Two materials were specified by the work assignment and two were to be selected on the basis of laboratory tests. Based on the results of the laboratory tests performed, and on the requirements of the work assignment, the following materials were selected for use in fabricating the "see through" lens caps to be delivered to the Government.

- (1) Polycarbonate-Lexan: Specified by work assignment.
- (2) Optical Glass: Specified by work assignment.
- (3) Slide Glass: This material had the best initial optical quality and was least affected by exposure to the blowing sand and dust environment (except for sapphire).
- (4) Sapphire: For eyepiece windows only. This material is too expensive to consider for use as objective windows and the cost is rather prohibitive for eyepiece windows. However, it was selected for the following reasons:

- (a) Sapphire showed no apparent degradation of optical quality after 12 minutes of sandblasting. Even though the initial optical quality is below that of other materials, it is available with better quality at increased cost. (Present samples have a flatness of 10 waves/in. of dia. and parallelism of .001 in./in. of dia. at a cost of \$11.50; it is available with flatness of 2 waves/in. of dia. and parallelism of .0005 in./in. of dia. at a cost of \$20.70.)

TABLE I

Raw Resolution Data for Windows (lp/mm)

Material	Duration of Exposure to Sand (Min.)				
	0	1	2	6	12
Slide Glass	4.6	4.3	4.3	4.1	3.5
Quartz	4.1	4.1	3.4	2.5	1.4
Sapphire	3.3	3.3	3.3	3.3	3.3
Optical Glass	4.3	4.2	4.1	3.2	2.6
Thick Tygon	-	-	-	-	-
Thin Tygon	0.5	0.5	0.3	0.3	0.3
Plexiglass	4.3	3.5	3.2	2.2	0.6
Lexan	3.5	2.6	2.5	0	-
Saran + Glass	4.1	1.4	N.T.	N.T.	N.T.
Saran	4.1	3.3	N.T.	N.T.	N.T.

N.T. = Not Tested.

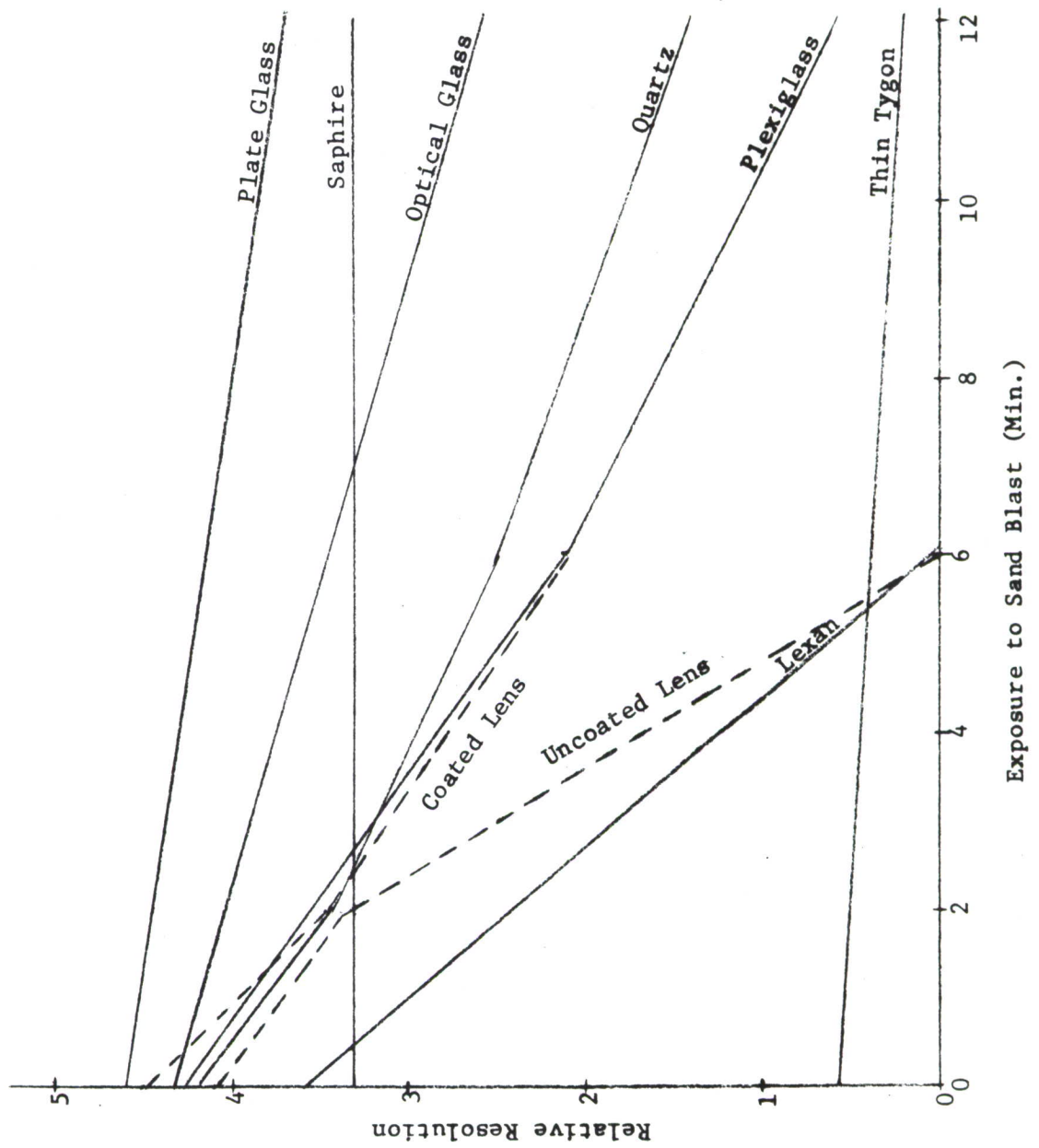


Figure 8a- Comparative Degradation of Materials & Lenses Tested.

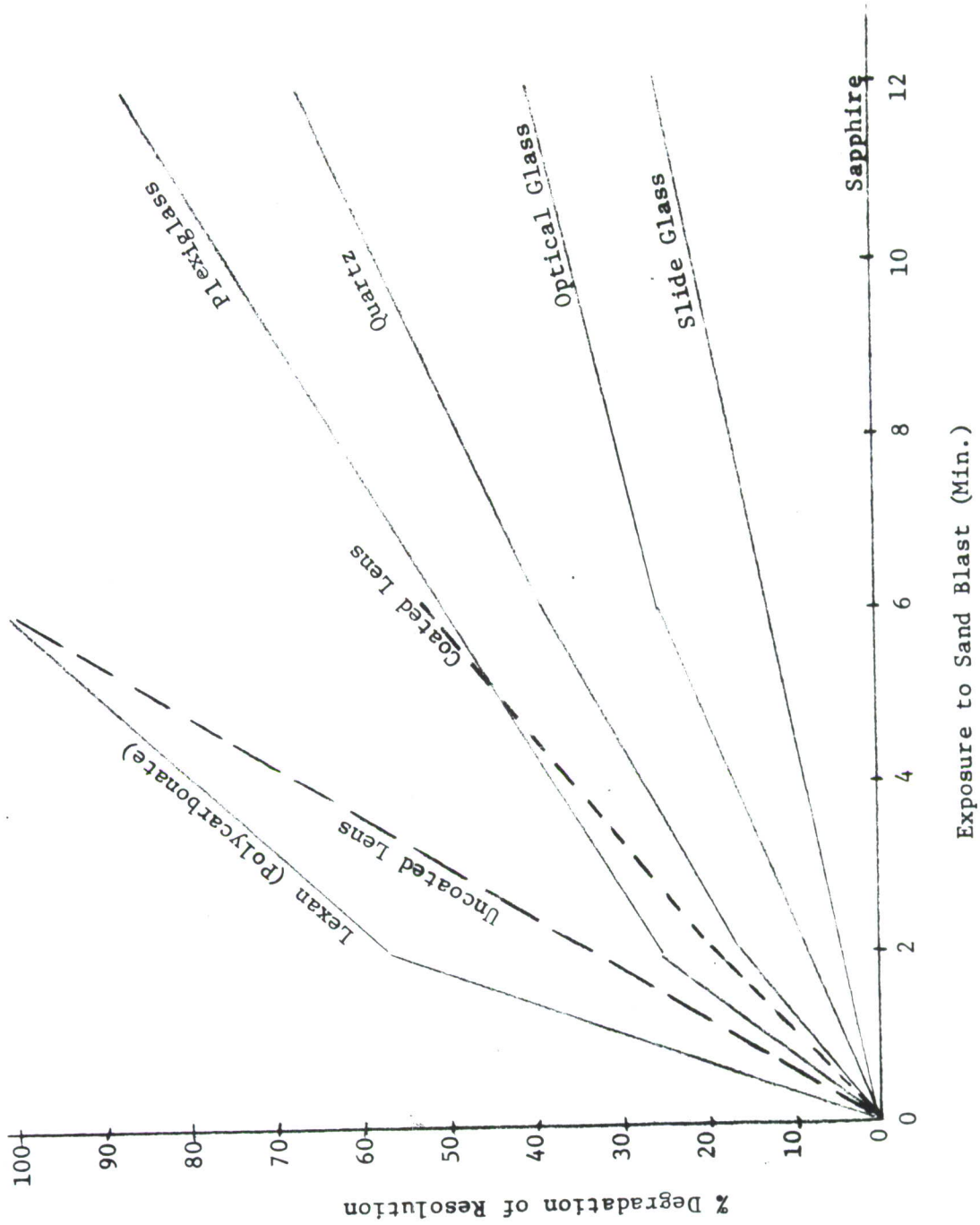
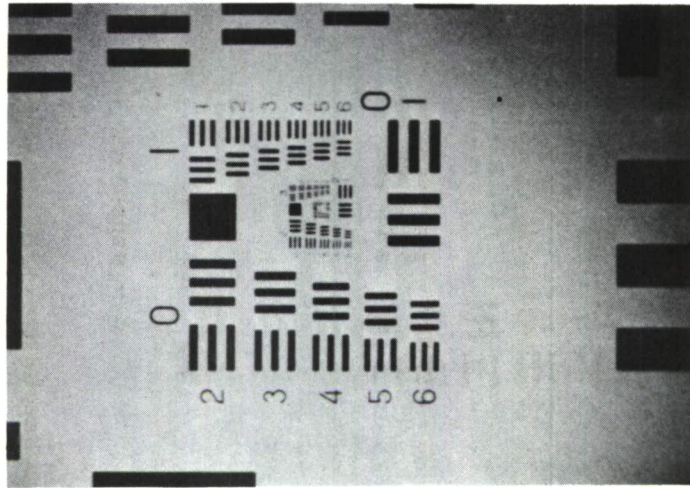
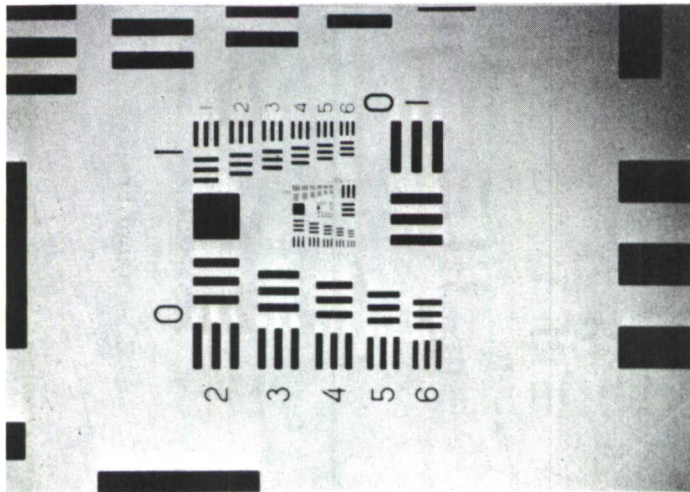


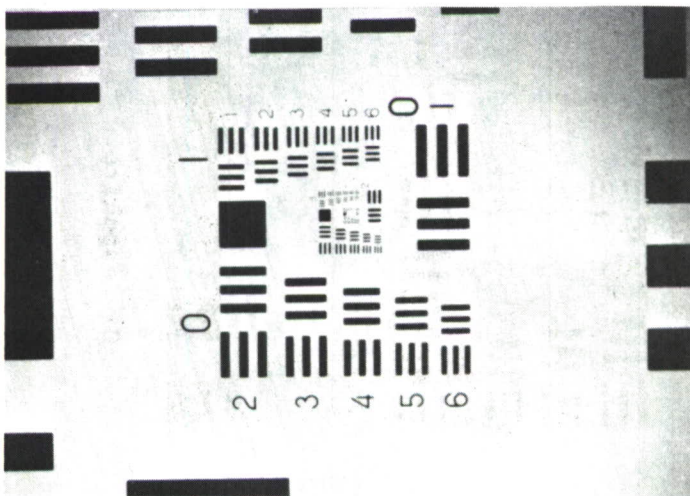
Figure 8b- Percent Degradation of Resolution (Normalized)



0 - Slide Glass

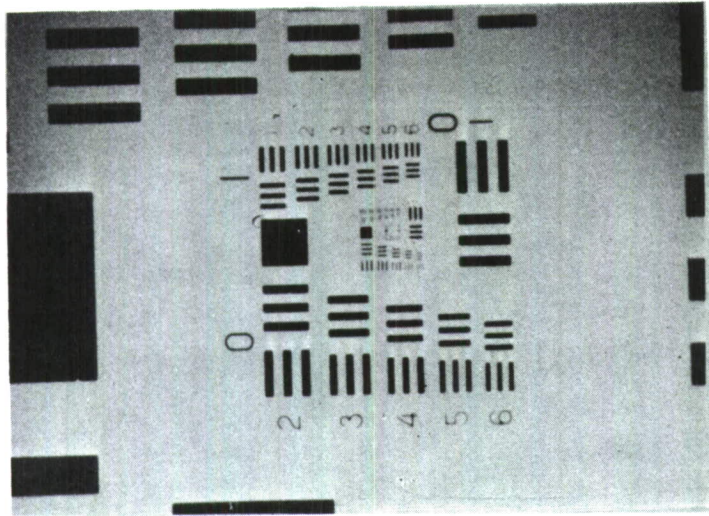


1 - Slide Glass

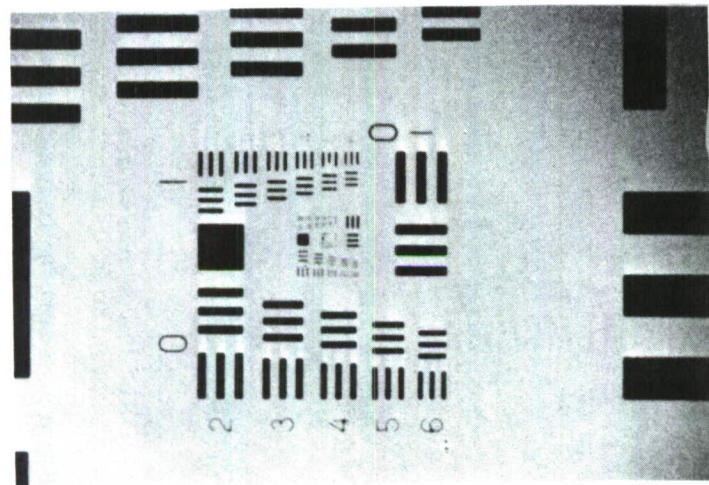


6 - Slide Glass

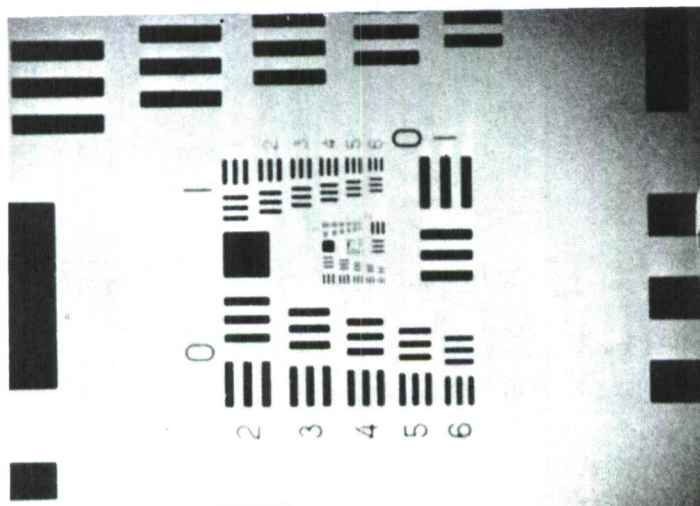
Figure 9 - Photographic Records, Image Degradation Slide Glass



6 - sapphire

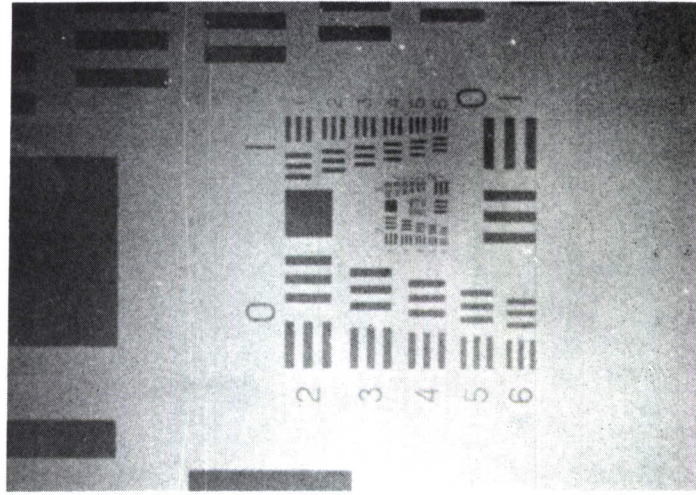


1 - sapphire

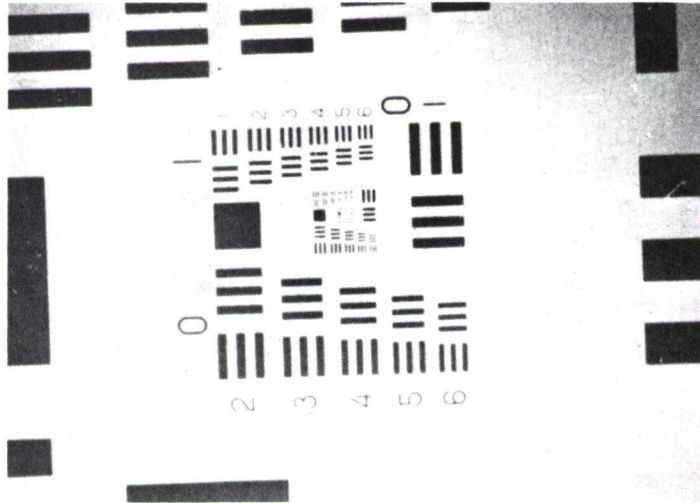


0- sapphire

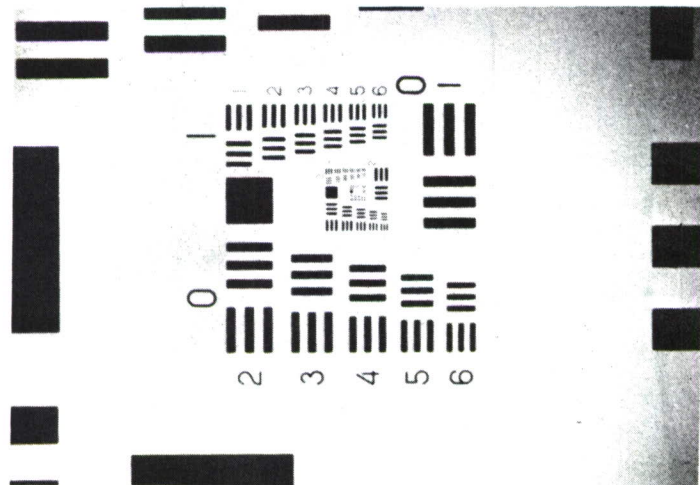
Figure 10 - Photographic Records, Image Degradation Sapphire.



6 - optical glass

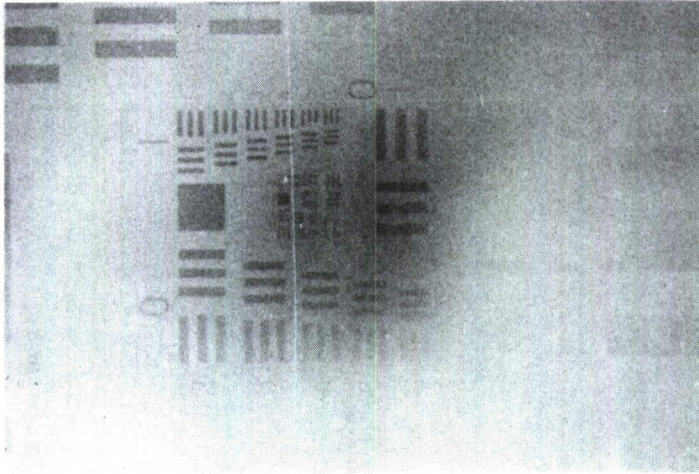


1 - glass (optical)

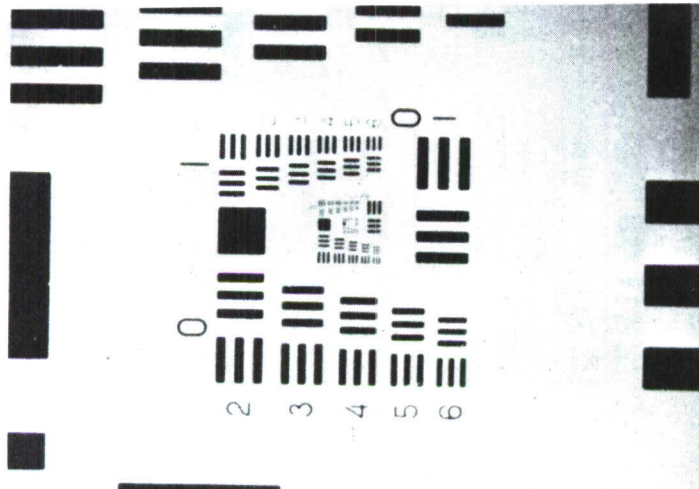


0 - optical glass

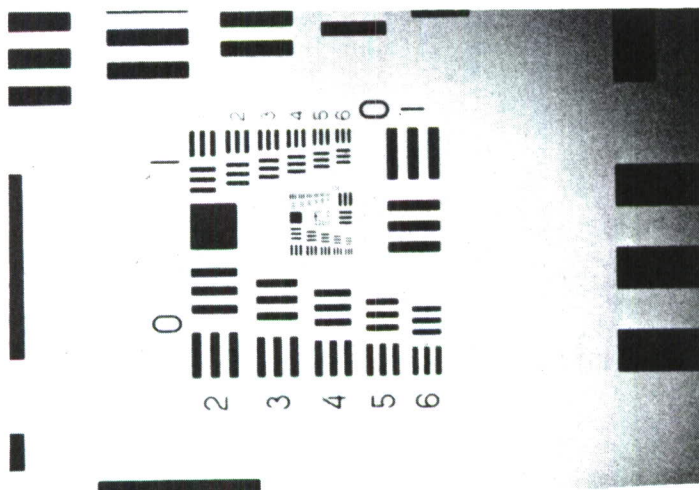
Figure 11 - Photographic Records, Image Degradation Optical Glass.



6- quartz

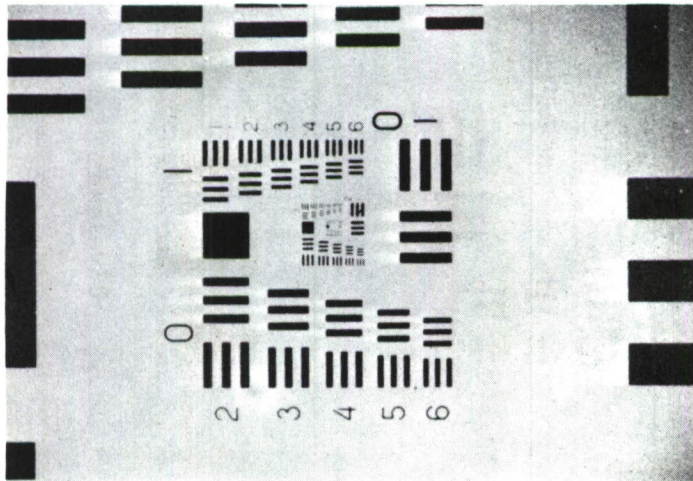


1- quartz

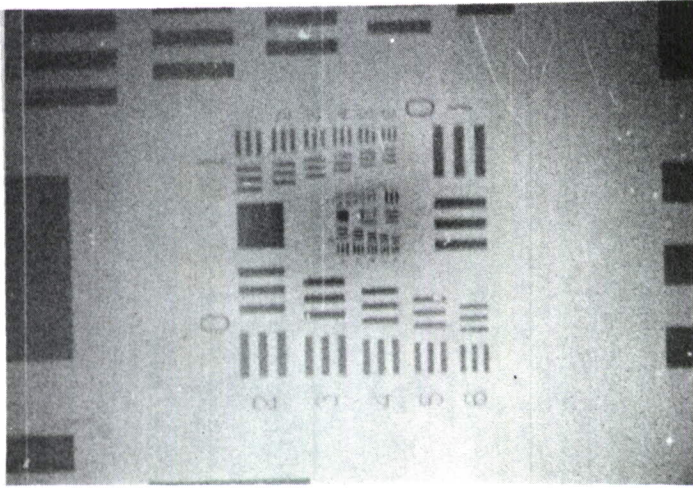


0- quartz

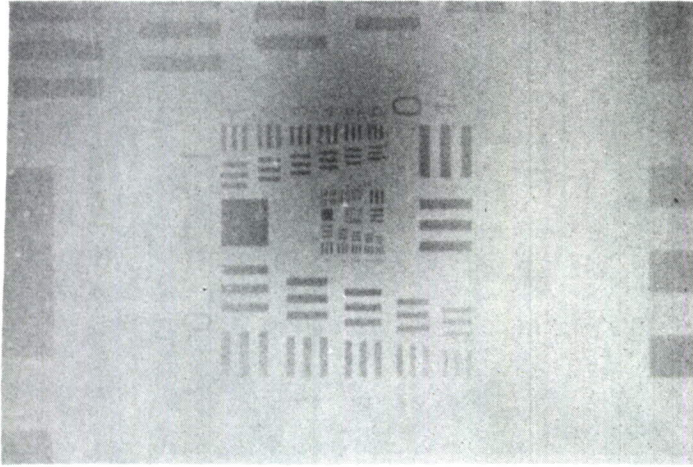
Figure 12 - Photographic Records, Image Degradation Quartz.



0 - plexiglass

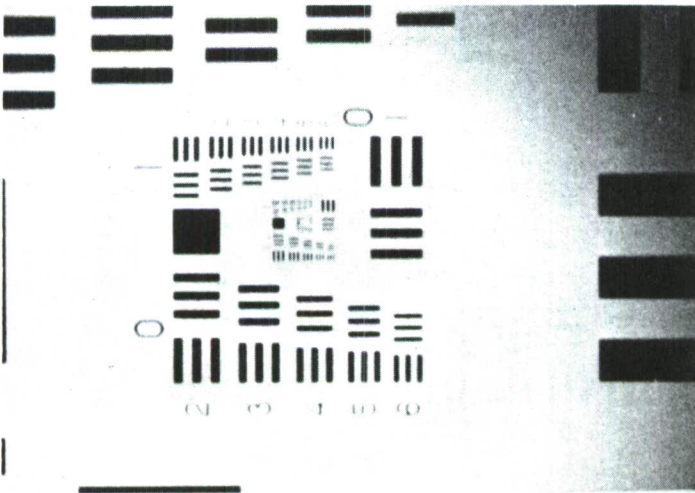


1 - plexiglass

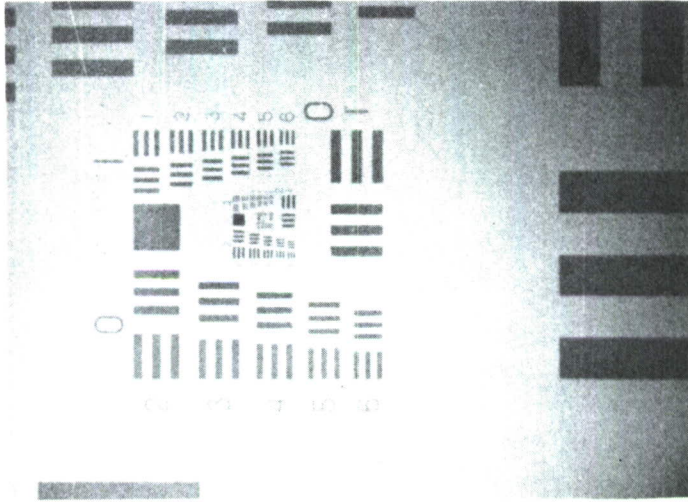


6- plexiglass

Figure 13 - Photographic Records, Image Degradation Plexiglass.



0 - lexan

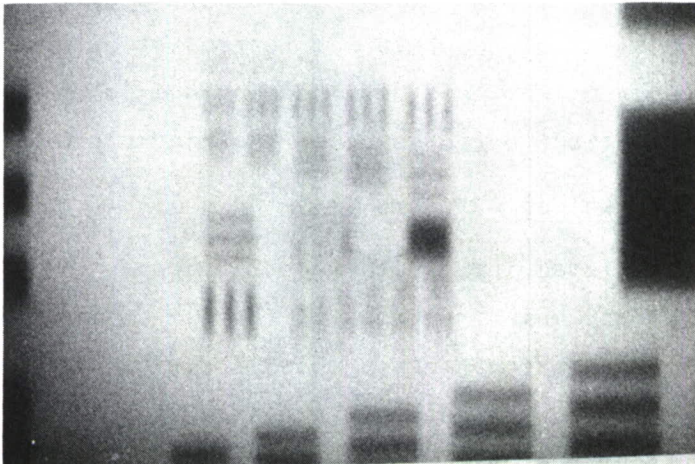


1 - lexan

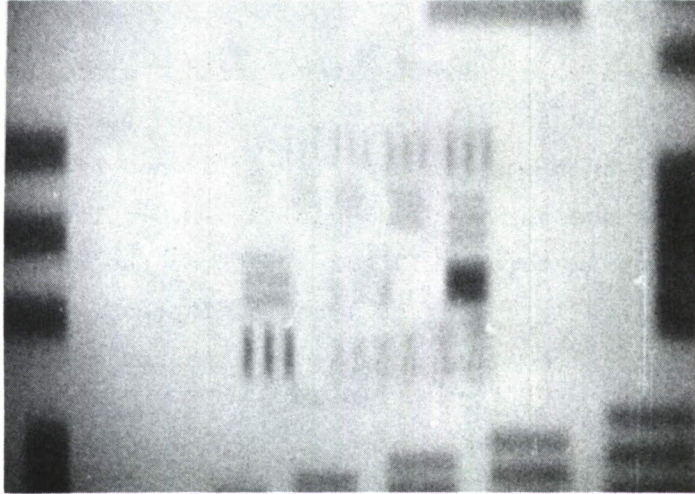


6 - lexan

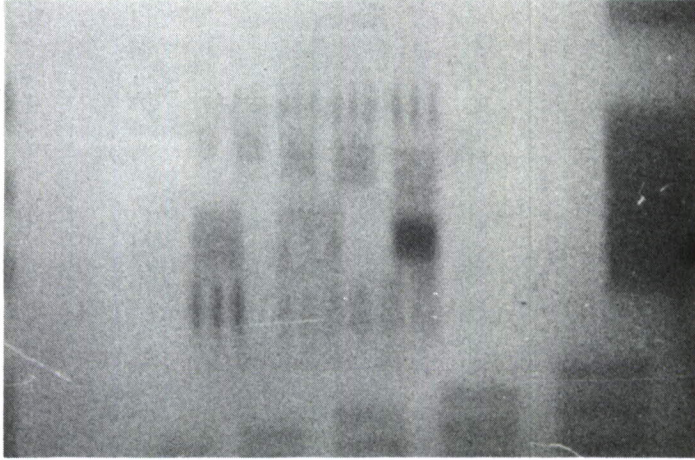
Figure 14 - Photographic Records, Image Degradation Lexan.



0- thin tygon



1- thin tygon



6 - thin tygon

Figure 15 - Photographic Records, Image Degradation Thin Tygon.

- (b) Tests reported in Section 3.6.1 indicated that it may be much more important to protect the eyepiece than the objective lens.
- (c) Present research and development work promises to reduce the cost of this material in the near future.

(5) Quartz: For objective dust cover only. Since the cost of sapphire prohibits its use (at this time) on the objective end, and since tests reported in Section 3.6.1 indicates that it is less important to protect the objective lens, this material was selected as an alternate. It is the material most likely to perform well in the dust chamber other than the slide glass and sapphire previously selected (excluding Lexan).

3.3.6 Results of Tests on Lenses

A test was conducted to compare the resolution degradation of two identical M-17 objective lenses, one with coating and one without. The resolution of the two lenses was measured initially and after 2 and 6 minutes using the technique outlined in Section 3.3.3. Table II lists the results, and Figures 16 through 19 are prints of the photographic records of the data initially and after 1 and 6 minutes. It is obvious from these that the optical coating acts as an abrasion resistant as well as an anti-reflective coating.

3.4 Design and Fabrication of Lens Caps for the M-17 Binoculars

It was necessary to design and fabricate adapters for the M-17 binoculars which would facilitate the easy mounting of the selected window materials. Each set of adapters was to consist of two objective lens caps and two eyepiece lens caps designed for simple on-off operation without affecting the optical performance of the binoculars.

3.4.1 Objective Lens Dust Cap Adapters

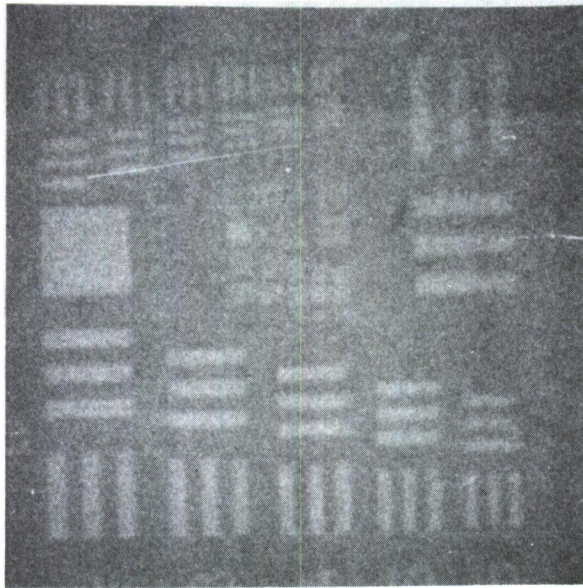
The M-17 binocular is equipped with objective caps that mount, by means of threads, over the main framework of the binoculars (see figure 20). These can be removed without any special tools by simply unscrewing the cap. The objective lens adapters are identical to the existing M-17 caps except that they are of slightly heavier stock aluminum and 3/16" longer to accommodate the window and gasket materials (see

TABLE II

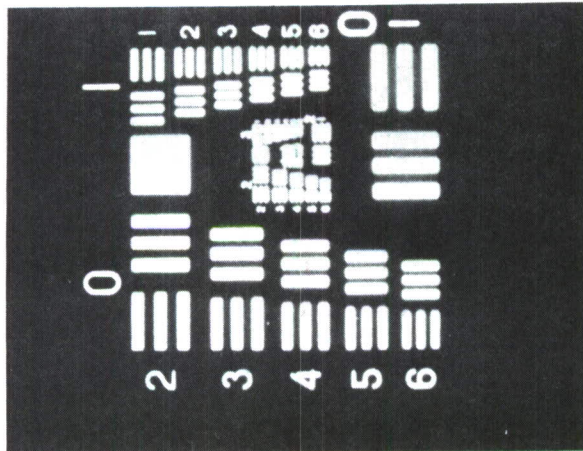
Resolution Data for Antireflection Coating

Material	Duration of Exposure to Sand (Min.)		
	0	2	6
Coated Lens	4.4	3.5	2.1
Uncoated Lens	4.1	3.4	-

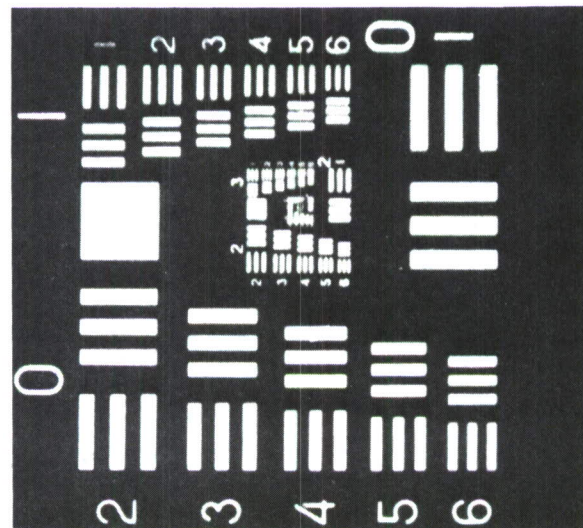
TECHNICAL LIBRARY
BLDG. 305
ABERDEEN PROVING GROUND, A.P.
STEAP-TL



6 Min.

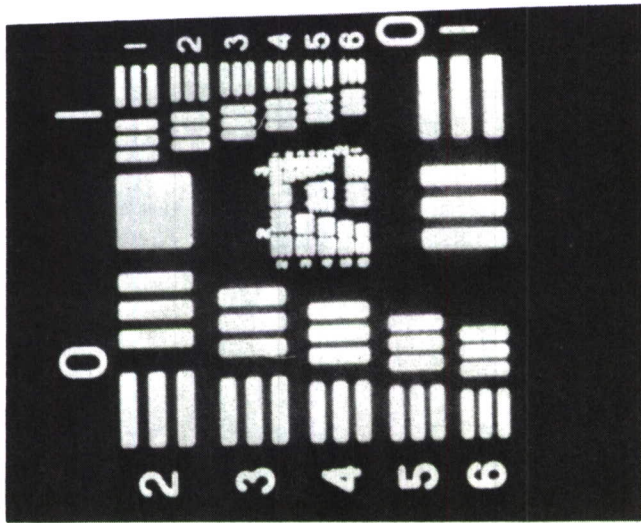


2 Min.

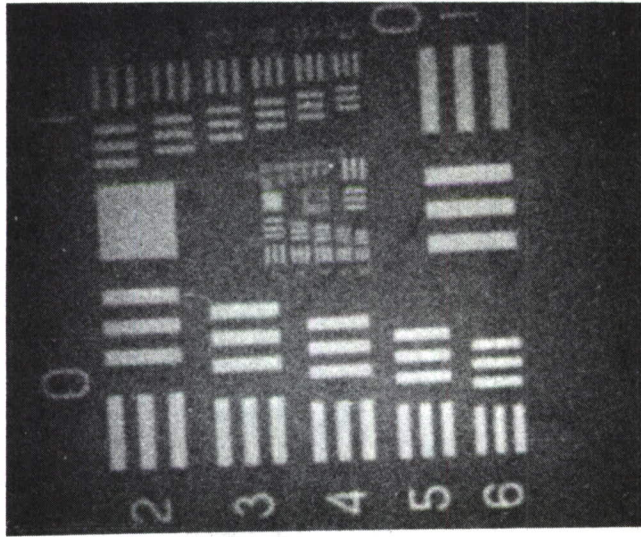


Initial

Figure 16 - Photographic Records, Image Degradation Coated Lens (Objective).

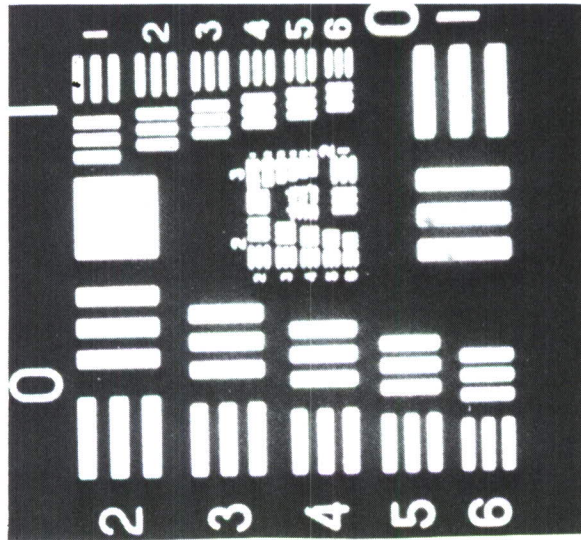


2 Min.

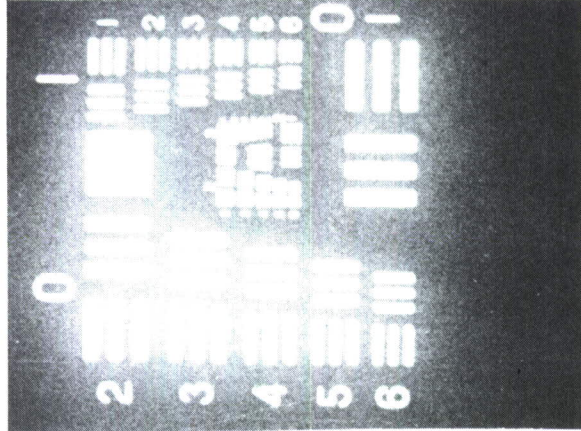


6 Min.

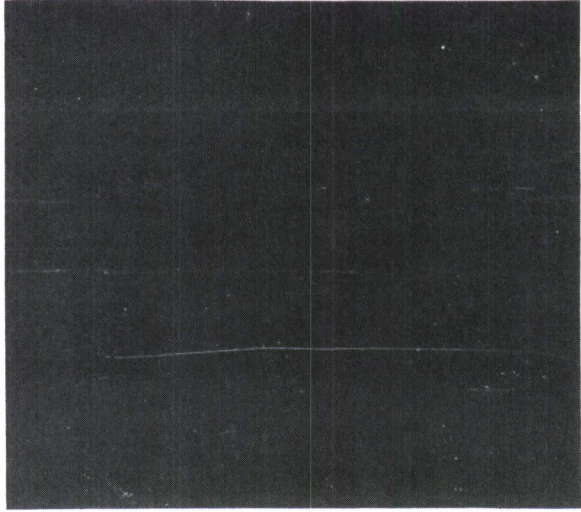
Figure 17 - Photographic Records, Image Degradation Coated Lens (Eyepiece).



Initial

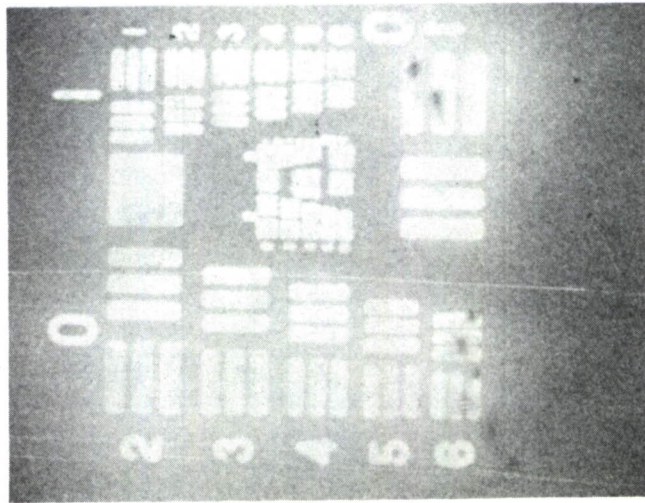


2 Min.

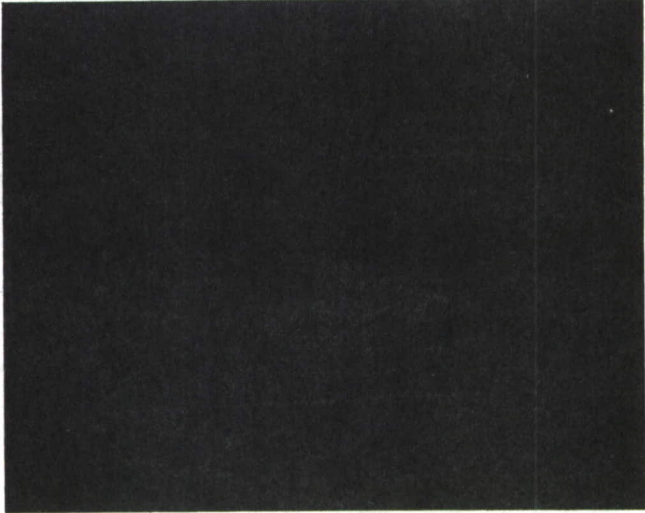


6 Min.

Figure 18 - Photographic Records, Image Degradation Uncoated Lens (Objective).



2 Min.



6 Min.

Figure 19 - Photographic Records, Image Degradation Uncoated Lens (Eyepiece).



Figure 20 - M-17 Binoculars with Objective Ring Removed.

figure 21).

3.4.2 Eyepiece Lens Cap Adapter

The M-17 binocular is equipped with eyecups that mount on the main framework of the binocular over each eyepiece lens to provide proper eye relief for the user. (See figure 22.) These too can be easily removed without any special tools by simply unscrewing them. The eyepiece dust cap adapters are designed to replace the existing eyecup while accommodating the window and gasket materials (see figure 23).

3.5 Lens Coating Removal Procedures

It was necessary to modify two M-17 binoculars by removing the anti-reflection coating from both the eyepiece and objective lens without deteriorating the optical quality of the lenses. To assure that the anti-reflection coating was completely removed, it was necessary to decement the acromatic lenses, remove the coating from both surfaces of the two component lens elements, and then recement the elements, taking care to preserve the matching and alignment of the elements.

3.5.1 Decementing Procedure

Each of the acromatic lenses was carefully scribed on the edge with a diamond stylus to mark their original alignment. They were raised to 300°C and held for 10 minutes to permit the thermal cement to soften. Then, while still hot, the lens elements were carefully separated.

3.5.2 Coating Removal Procedure

The following procedure was recommended by the manufacturer of coated lenses for removal of the anti-reflection coating: (1) fill a 250 cc beaker with commercial grade sulfuric acid (H_2SO_4); (2) add about 4 teaspoons of boric acid (H_3BO_3), amount is not critical; (3) mix thoroughly and place coated lens in solution at room temperature; (4) heat the solution (with lens) to 98°C (but do not boil!) and maintain the temperature for about 15 minutes; (5) allow the solution (with lens) to cool to room temperature, remove and wash lens thoroughly; (6) examine lens for traces of coating, if not completely removed, repeat the process.

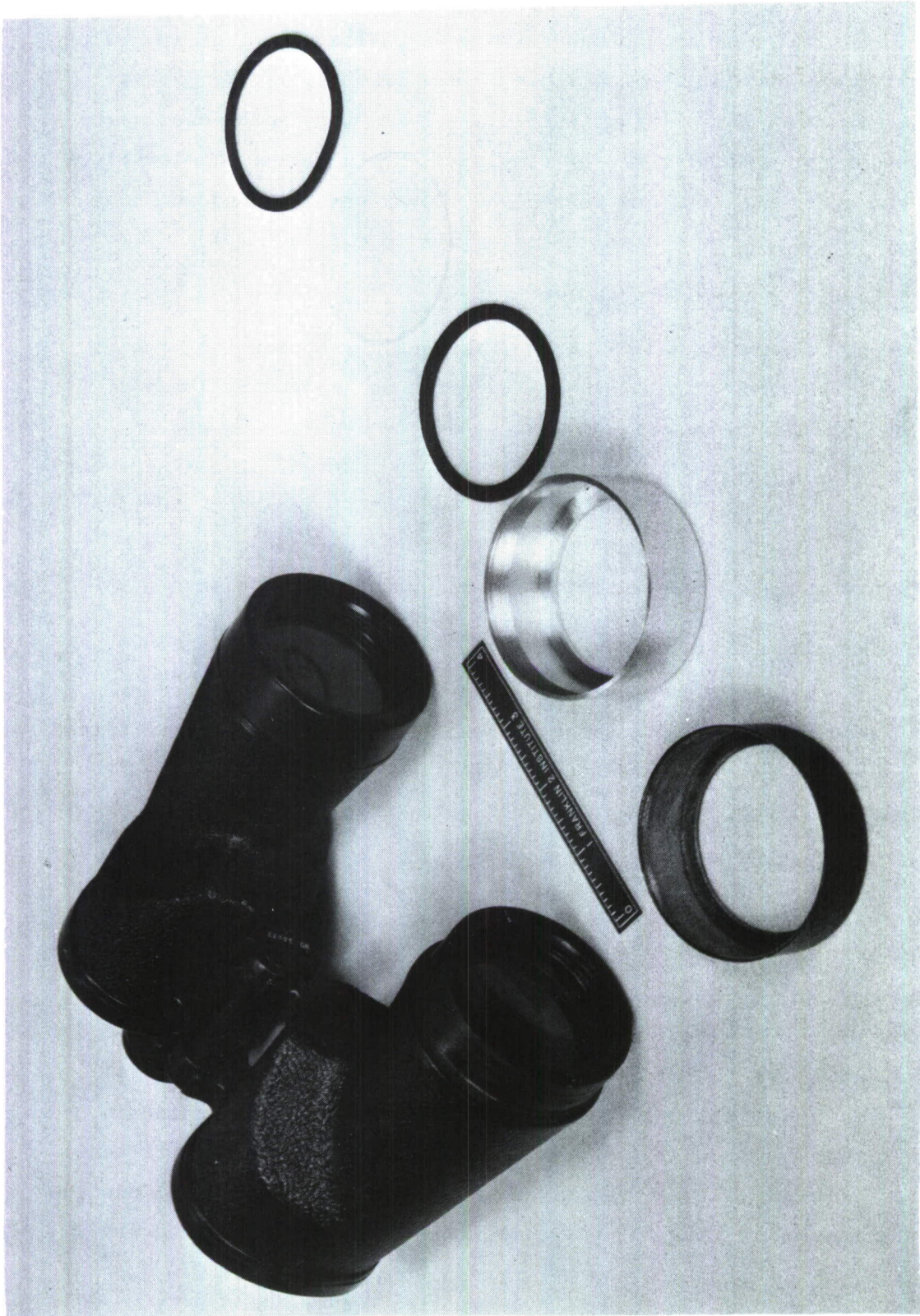


Figure 21 - M-17 Binoculars with Original Objective Cap, Special Adapter Cap, "See Through" Material and Gaskets.

figure 21).

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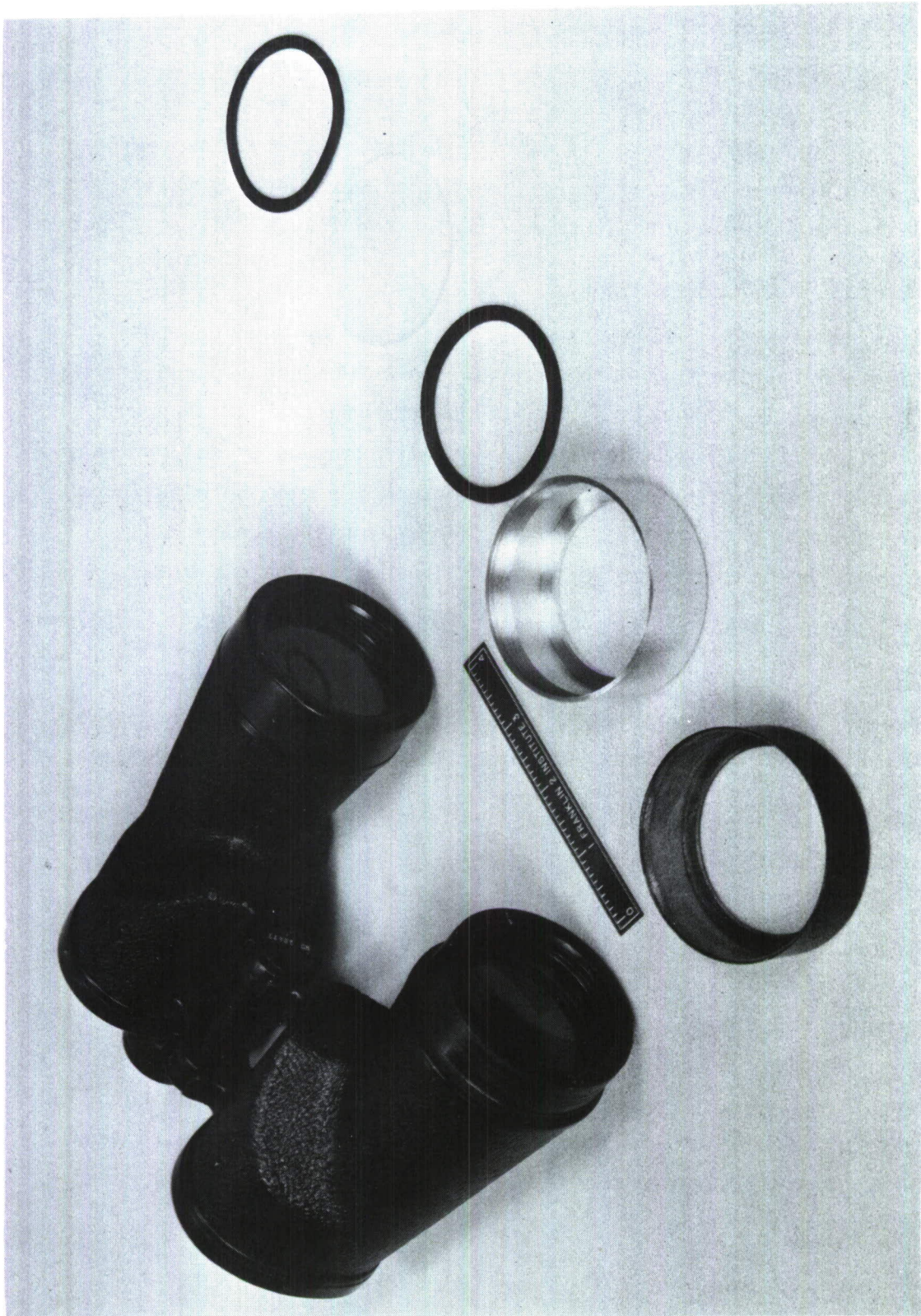


Figure 21 - M-17 Binoculars with Original Objective Cap, Special Adapter Cap, "See Through" Material and Gaskets.



Figure 22 - M-17 Binoculars with Eyepiece Cap Removed.



Figure 23 - M-17 Binoculars with Eyepiece Cap Adapter,
"See Through" Material and Gaskets.

3.5.3 Preliminary Tests

Preliminary tests were performed on inexpensive lenses with anti-reflection coating, in order to determine that the above outlined procedure would not deteriorate the optical quality of the lenses. The expected deterioration of quality would result from a degradation of the surface texture that would produce a reduction in the resolution of the lenses. In order to verify that such degradation did not take place, resolution measurements were made on three test lenses, before and after removal of the anti-reflection coating. No degradation in resolution was observed. The measurement procedure is outlined in Section 3.3.3 of this report.

It should be pointed out that certain degradation in optical quality is inherent with removal of the anti-reflection coating, namely that improvement in quality provided by the coating. The coating provides two improvements which will necessarily be lost: (1) the coating provides better light gathering capability by reducing losses due to reflection, and (2) the coating greatly reduces secondary images due to reflections.

3.5.4 Realignment

After the lenses have been decemented, have had the coating removed, have been recemented, and have been replaced in the binoculars, the optical alignment of the binoculars must be adjusted. This was performed on a standard optical alignment bench in accordance with specifications outlined in Military Specification TM9-1580, T038-1-1, and MIL-0-13830A.

3.6 Additional Tests

3.6.1 Effects of Degraded Windows

A test was conducted to estimate the effects of degraded windows at the objective lens as compared with the eyepiece lens. It was anticipated that abrasive degradation of the objective dust window would have less effect on a scene than the same degradation of the eyepiece dust window. To estimate this effect the apparatus described in Section 3.3.3 was set up using a small convex lens. Measurements of

resolution were made under the following conditions: (1) with no window, (2) with an abrasion degraded window between the scene (resolution chart source) and the lens simulating the objective dust window (point a in Figure 6), and (3) with the same window between the lens and the image (frosted screen) simulating the eyepiece dust window (point b in Figure 6). The degraded window was a sample of the slide glass which had been exposed to the blowing sand and dust environment for 8 minutes. Table III lists the results, and Figure 24 contains prints of the Photographic records. It appears that abrasive degradation of the objective dust window will interfere less with a viewed scene than the same degradation of the eyepiece dust window. This observation was verified by reproducing the conditions with M-17 binoculars in operational tests.

3.6.2 Effect of Degraded Lenses

A test was conducted to estimate the effect of abrasion degradation of the lenses themselves. It was anticipated that degradation of the lenses would not have the same effect as degradation of windows. To estimate this effect the apparatus described in Section 3.3.3 was set up using two objective lenses from M-17 binoculars, one coated and one not coated. Measurements of resolution were made under the following conditions (1) initially with no abrasion degradation of either lens surface, (2) with the abrasive degradation on the lens surface toward the resolution chart (to simulate the objective lens), and (3) with the abrasive degradation on the lens surface toward the camera (to simulate the eyepiece lens). Measurements were taken for degradations resulting from 0, 2 and 6 minutes of exposure in the dust chamber.

Table IV lists the results, and Figures 16 through 19 contain prints of the photographic results. Figure 16 shows the results of the coated lens positioned to simulate the objective lens, and Figure 17 shows the results of it positioned to simulate the eyepiece lens. Figure 18 shows the results of the uncoated lens positioned to simulate the objective lens, and Figure 19 shows the results of it positioned to simulate the eyepiece lens. The data indicates that degradation of the coated lens in the objective lens simulation degrades the resolution approximately the same as the use of a plexiglass window (compare

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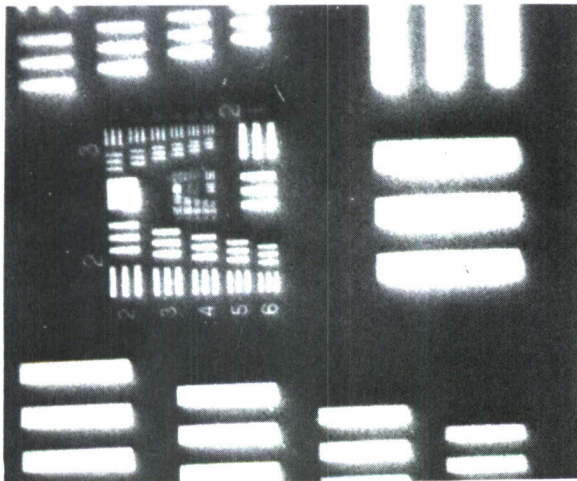
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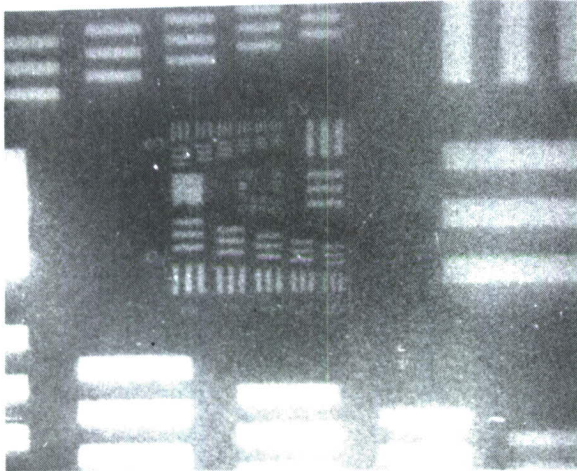
TABLE III

Resolution Data for Degraded Windows

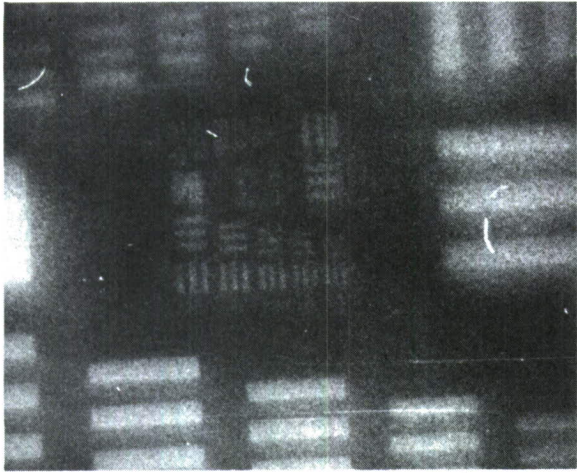
Condition	Resolution
No Window	4.6
Objective Window	4.2
Eyepiece Window	3.3



No Window



Objective



Eyepiece

Figure 24 - Photographic Records, Image Degradation Degraded Window at Objective & Eyepiece Location.

TABLE IV

Resolution Data for Degraded Lenses

Exposure Time (Min.)	Coated Lens		Uncoated Lens	
	objective	eyepiece	objective	eyepiece
0	4.4	4.4	4.1	4.1
2	3.5	3.6	3.4	3.5
6	2.1	2.6	-	0.4

with Table I), and approximately the same as the use of a quartz window in the eyepiece simulation. In both cases the degradation of the uncoated lens was greater.

Hardness measurements show no appreciable difference between the coated (434 Kg/mm^2) and the uncoated (431 Kg/mm^2) as measured on the Knoop scale.

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