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Report on

Underwater Visibility

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
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A B S T R A C T

An initial study has been made of the effect on the visibility of underwater objects as seen by a diver working under water, of placing optical filters in either the diving lamp or the diving helmet. It appears to be quite conclusive that filters capable of transmitting the orange or yellow wavelengths of visible radiation improve the visibility of the submerged objects.

AUTHORIZATION

1. This problem has been authorized by Bureau of Construction and Repair letter S94-(8)-(1) (ME) of 24 September 1936.

STATEMENT OF PROBLEM

2. The deep sea diver, when working under water, is at all times laboring under many handicaps, the greatest difficulty undoubtedly being his inability to see clearly under average working conditions. The visibility ranges from a point at which the diver sees his work quite clearly to a point where the water contains suspended mud and silt in such quantities that the diver works in total darkness. The Experimental Diving Unit at the Washington Navy Yard has been interested in the problem of improving the diving visibility and has accumulated considerable information, both through inquiry and experimentation. Wishing to extend this investigation, the Diving Unit requested aid of the Naval Research Laboratory and the work described in this report is a result of the cooperation extended to the Diving Unit.

METHODS

(a) Preliminary Experiments

3. As a preliminary experiment, a series of glass optical filters was taken to the Experimental tank where submerged objects, illuminated with a 250-watt incandescent lamp, were viewed through the observation port both with the filters in the line of vision and removed. The opinion of a number of observers appeared to be that only those filters the maximum transmission of which was in the yellow or orange were of value, filters in the greens and blues being detrimental to good vision. Of this series of filters, three were chosen for extended observations, namely Corning #338 "Noviol" Shade C (lemon yellow), Corning #246 (amber shade) which was especially ground and polished by the Optical Shop, Navy Yard, Washington, D.C., and Corning HR Red (orange red).

4. These three filters were given to fifteen of the most experienced Naval divers who observed objects in the diving tank and used them in arc welding operations. The filters were again taken under the surface of the river to observe dock-piling when illuminated with the standard diving lamp. The opinion of the observers gave preference to Corning "Noviol" Shade C as the filter which improved visibility to the greatest extent.

(b) Photographic Experiments

5. To determine whether or not a more definite choice of filters could be made, the problem was approached from the photographic standpoint. A corroded steel plate with holes punched in it and nuts and bolts attached to it was submerged in the Experimental Tank in such a position as to be visible through an observation port. This plate was then illuminated by the desired source of radiation so placed that through the port it was not visible to the eye or camera. Photographs using Wratten and Wainwright Panchromatic plates were taken under constant conditions of turbidity, distance and times

of exposure. In the photographs, the sharpness of the details of the corroded plate with its nuts and bolts was taken as a criterion of the value of the type of illumination as a means of underwater illumination. A series of 14 photographs was taken. From Plate 1 through Plate 7 the submerged object was placed 30 inches from the observation port and the source of illumination placed 20 inches from the plate. The tank was emptied and then filled with clean city water. However, due to the activities of the divers in arranging the lamps and plate, considerable sediment was stirred up, much of which remained in suspension during the experiments. The divers present during the tests pronounced the water clearer than water in which submarine work is usually carried on.

6. A measurement of the intensity of light from a tungsten bulb situated in the tank 150 centimeters from the port with the water in the tank and again when the tank had been emptied gave an approximate value for the coefficient of absorption λ of the water, λ being defined by

$$I = I_o \epsilon^{-\lambda (x-x_1)}$$

where I and I_o are the intensities of the light, as measured by a Weston Exposure Meter, with the tank full and empty, and $(x - x_1)$ the thickness of water between the meter and source. The value of λ was found to be 0.0188.

7. Plates 8 and 9 exhibit the appearance of the submerged plate after it had been moved a distance of 60 inches from the observation port, with the light source 50 inches from the object. Plates 10 through 14 show the corroded plate after the tank water had been changed and the plate moved again to within 30 inches of the observation port.

DATA OBTAINED

(a) Examination of Photographic Plates

8. Plate 1 shows the corroded steel plate in the tank illuminated with a 250-watt "Photoflood #1" lamp placed in the diving lamp casing with no optical filters in the light path. To the eye, the intervening water appeared to be filled with a bright haze due to the light scattered by the suspended matter. This bright haze confused very markedly the vision of the person looking into the observation port. The sharp edges of the punched holes, the slots in the bolt heads and the edges of the nuts became less distinguishable. However, after exchanging the clear bulb in the diving lamp for a 250-watt amber colored bulb furnished by Morse & Company, makers of diving equipment, the bright haze between the observer's eye and the submerged object became much less and the details of the plate stood out more clearly. Plate 2 shows the photographic effect of this type of illumination. Plate 15 exhibits the optical transmission of the glass from which the lamp bulb is made.

9. The diving light was replaced with a 250-watt "Photoflood" lamp #1 and an optical filter made of Corning #246 glass placed in front. This

glass is a yellowish amber color and its optical characteristics are shown in Plate 16. Plate 3 exhibits the appearance of the object under water when illuminated by the radiation through the #246 glass. The bright scattered light was absent and the details of the plate stood out quite clearly.

10. Plate 4 shows the submerged steel plate illuminated by radiation from the diving lamp in front of which was a filter of Corning "Noviol" Shade C (lemon yellow), the optical characteristics of which are shown on Plate 17. Again the mass of scattered light was absent and the details of the plate appeared to become more discernible.

11. From the above described tests, one can say quite definitely that any one of the filters tried improved the visibility of the corroded plate with its nuts and bolts when placed in front of the diving lamp. However, to say which filter was the best is much more difficult and a more extended investigation under more varied conditions is necessary.

12. Plates 5, 6 and 7 were taken with the submerged object illuminated by the clear bulb "Photoflood" #1 lamp placed in the casing of the standard diving lamp and the optical filters placed before the lens of the camera. Plate 5 shows the effect of the Corning "Noviol" Shade C, Plate 6 Corning #246, and Plate 7 a filter made of a reddish amber-colored glass called Corning HR Red. As one would expect, it appears both from visual observation and from photographic examination that it is a matter of indifference, from an optical standpoint, whether the filter is placed in front of the lamp or held before the eye.

13. Plate 8 shows the submerged plate when it has been moved back from the port to a distance of 60 inches and illuminated by the clear diving lamp placed 50 inches from it. The water was quite full of suspended matter due to the activities of the divers working in the tank; however, the silt was allowed to settle until a constant condition of turbidity was reached.

14. When the plate was observed through the port illuminated by the clear diving lamp, the scattered light was so intense that the eye was blinded to such an extent that the details of the plate were quite indistinct. Three filters, namely Corning "Noviol" Shade C, Corning #246 and Corning HR Red, were in turn placed before the diving lamp. In each case, the bright scattered light became much less pronounced and the details of the plates became more distinguishable, although of course much less so than when the plate was 30 inches from the port.

15. Plate 8 is a photograph of the submerged object illuminated with the clear diving lamp, while Plate 9 shows the submerged plate illuminated by radiation from the diving lamp which has passed through the "Noviol" Shade C filter. With this illumination, the nuts and bolt heads were more clearly seen.

(b) <u>Experiments with the diving tank filled with river water</u>

16. A series of experiments were planned to test the effect of the orange and yellow optical filters on the visibility of objects under water water containing enough suspended sediment to simulate extremely poor diving

conditions. The diving tank was filled with water directly from the river and the corroded plate and the sources of illumination were replaced therein.

17. Nothing could be seen through the port unless the plate was within 6 inches of the port. The intervening water was a mass of brilliant light due to the scattering of the incident beam. Photographic records were hopeless under these conditions.

18. The water was diluted to approximately 50% of the original turbidity, but the visibility was not improved. The experiments were abandoned.

(c) Appearance of Submerged Objects When Illuminated by Radiation from a Sodium and a Mercury Light.

19. The tank was emptied and refilled with clean city water, the corroded steel plate placed 30 inches from the port and the source of illumination 20 inches in front of the plate. The water appeared to have less suspended matter in it than in the previous work, consequently the data obtained cannot be compared with that previously obtained.

20. Plate 10 shows the appearance of the submerged plate when illuminated with a large General Electric sodium vapor lamp enclosed in a watertight casing. To the eye, the plate and its details were very clearly visible and the scattered light between the observer and the object did not appear to be very intense. Plate 11 shows the submerged object again illuminated with the radiation from the sodium light with an Eastman K-3 filter in front of the camera lens. There is no difference in the contrast shown by the photographic plates in these two exposures.

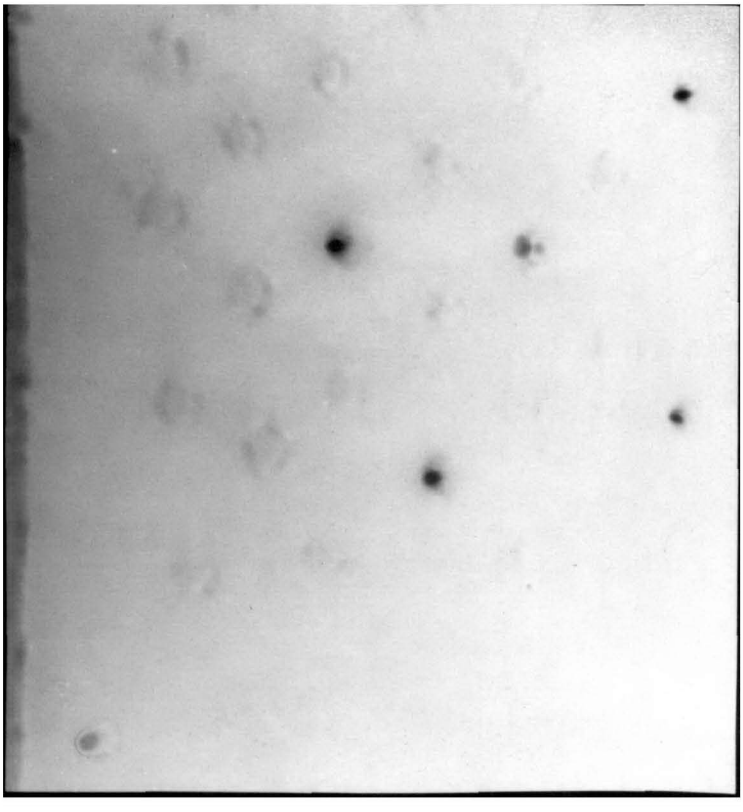
21. Plate 12 shows the submerged object again illuminated by the clear diving lamp in front of which was filter of Corning "Noviol" Shade C. A comparison of Plates 11 and 12 shows the two sources of illumination to be of about equal value, which observation is supported by visual trials. In Plate 13 an Eastman K-3 filter was placed in front of the camera lens with no noticeable effect.

22. Finally, Plate 14 shows the submerged plate illuminated by radiation from a high power G-E Mercury vapor lamp enclosed in a watertight casing. As was expected, to the eye the details of the plate were quite indistinct, since the eye loses its sensitivity quite rapidly as the wavelength of radiation decreases; and, as is well known, the mercury arc is rich in radiation in the blue region. The photographic plate, which is sensitive to the lower wavelengths, would be expected to show about as much contrast as with other types of illumination.

CONCLUSIONS

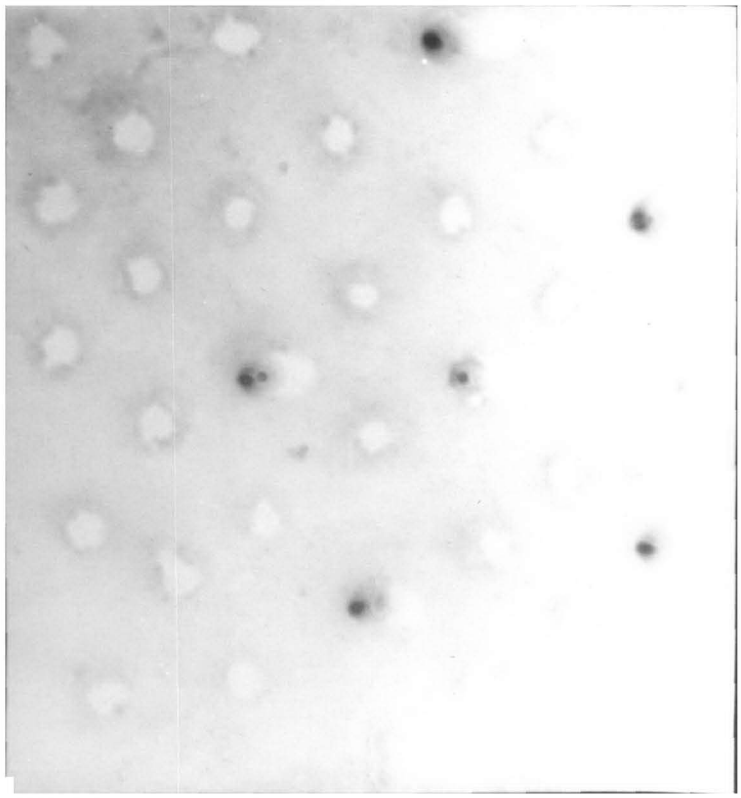
23. It appears to be quite well established in this series of experiments that an optical filter with maximum transmission in the yellow materially improves the visibility of submerged objects as seen by a diver working under ordinary conditions. However, one must realize when the quantity of sediment in the water exceeds a certain value, the diver works in darkness and no optical filter can be of assistance.

24. Further experiments are in progress to determine more accurately the optical characteristics of the filter which will improve the visibility of submerged objects to the greatest extent.



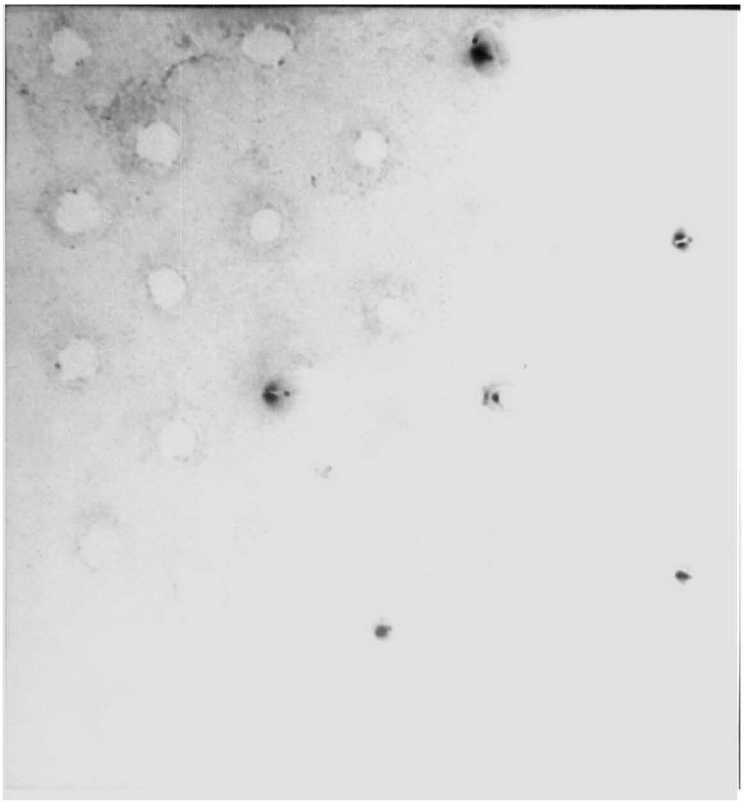
SOURCE OF ILLUMINATION – PHOTO FLOOD 250 WATTS – NO FILTERS IN THE LIGHT PATH. TO THE EYE THE FIELD APPEARS VERY BRIGHT, THE PLATE CAN BE SEEN, BUT THE SCATTERED LIGHT MAKES IT DIFFICULT TO PERCEIVE THE DETAILS OF THE PLATE.

PLATE I



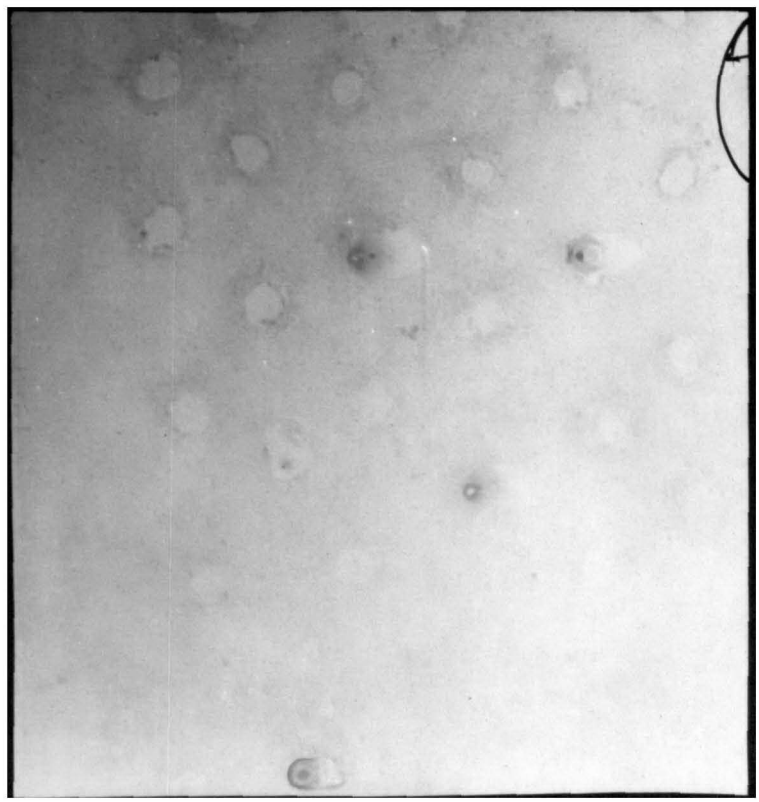
SOURCE OF ILLUMINATION - AMBER COLORED BULB, 250 WATT FURNISHED BY MORSE & COMPANY FOR THE NAVY DIVING LAMP. THE PLATE WAS QUITE PLAINLY SEEN BY THE EYE.

PLATE 2



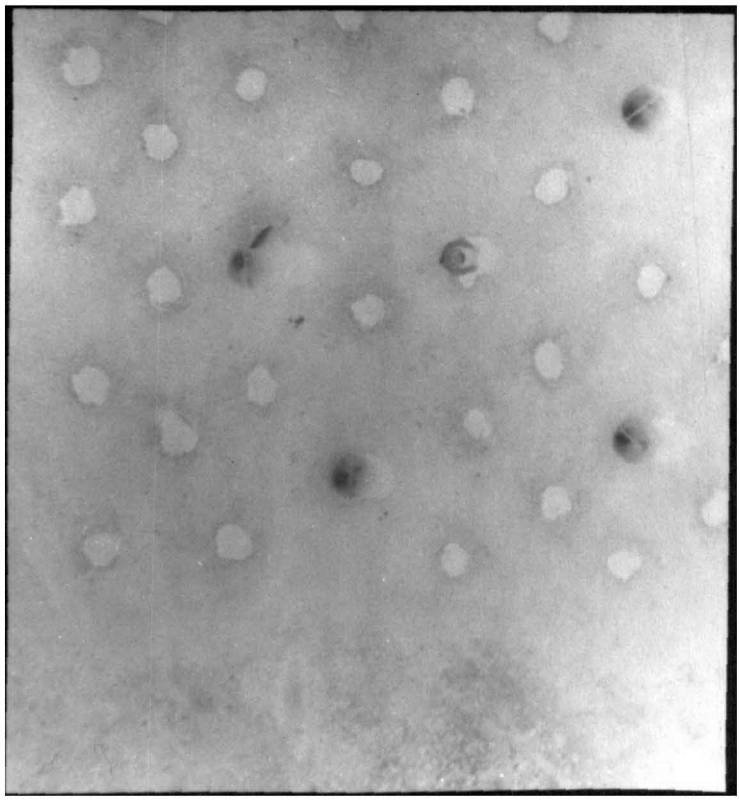
SOURCE OF ILLUMINATION - "PHOTO FLOOD" 250 WATTS - A FILTER OF A GLASS LABELED "CORNING #246" SPECIALLY POLISHED BY THE OPTICAL SHOP, NAVY YARD, WASH. D.C., WAS PLACED IN FRONT OF THE SOURCE. TO THE EYE THE DETAILS OF THE PLATE BECAME CLEARER WHEN THE FILTER WAS PLACED OVER THE LAMPS.

PLATE 3



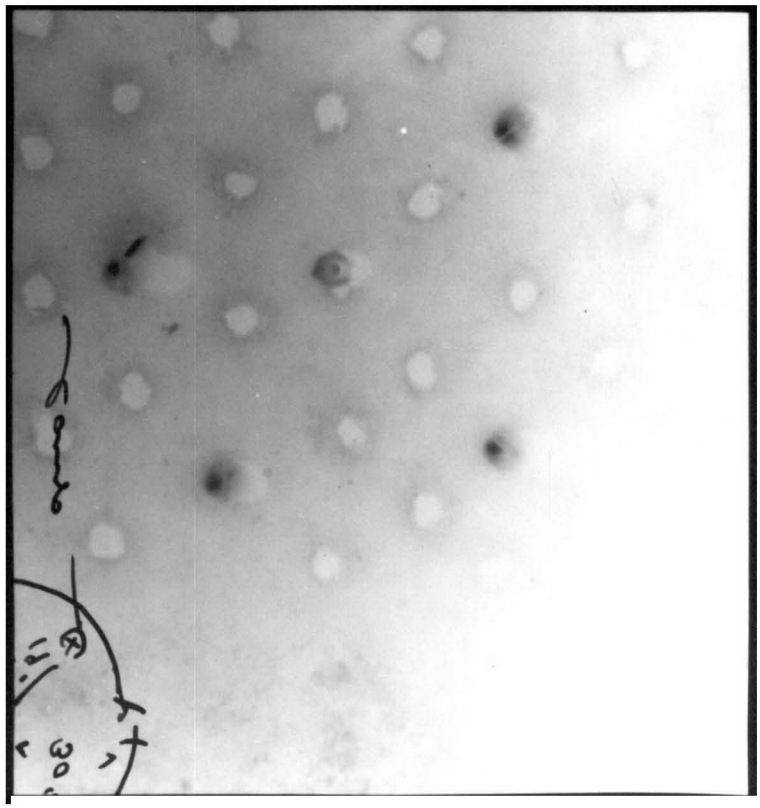
SOURCE OF ILLUMINATION - "PHOTO FLOOD" 250 WATTS - A FILTER OF CORNING "NOVIAL" SHADE "C" (LEMON YELLOW) WAS PLACED IN FRONT OF THE LIGHT SOURCE - THE MASS OF SCATTERED LIGHT BECAME LESS AND THE DETAILS OF THE PLATE APPEARED TO BECOME MORE DISCERNIBLE, HOWEVER, THEY COULD BE SEEN ONLY WITH DIFFICULTY.

PLATE 4



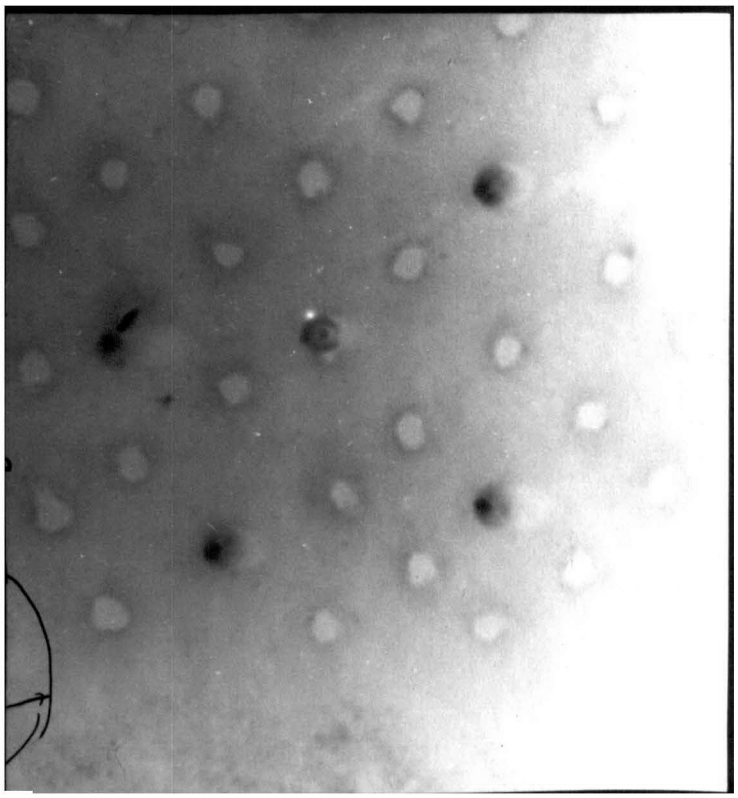
SOURCE OF ILLUMINATION - "PHOTO FLOOD" 250 WATTS - A FILTER OF CORNING "NOVIAL" SHADE "C" (LEMON YELLOW) WAS PLACED IN FRONT OF THE CAMERA LENS. WHEN THE EYE WAS PLACED IN THE POSITION OF THE CAMERA LENS THE SCATTERED LIGHT IN THE WATER BECAME LESS AND THE DETAILS OF THE PLATE BECAME CLEARER.

PLATE 5



SOURCE OF ILLUMINATION - "PHOTO FLOOD" 250 WATTS - A FILTER OF "CORNING #246" SPECIALLY POLISHED BY THE OPTICAL SHOP, NAVY YARD, WASH. D.C., WAS PLACED IN FRONT OF THE CAMERA LENS. WHEN THE EYE WAS PLACED IN THE POSITION OF THE CAMERA LENS THE SCATTERED LIGHT IN THE WATER BECAME LESS AND THE DETAILS OF THE PLATE BECAME CLEARER.

PLATE 6

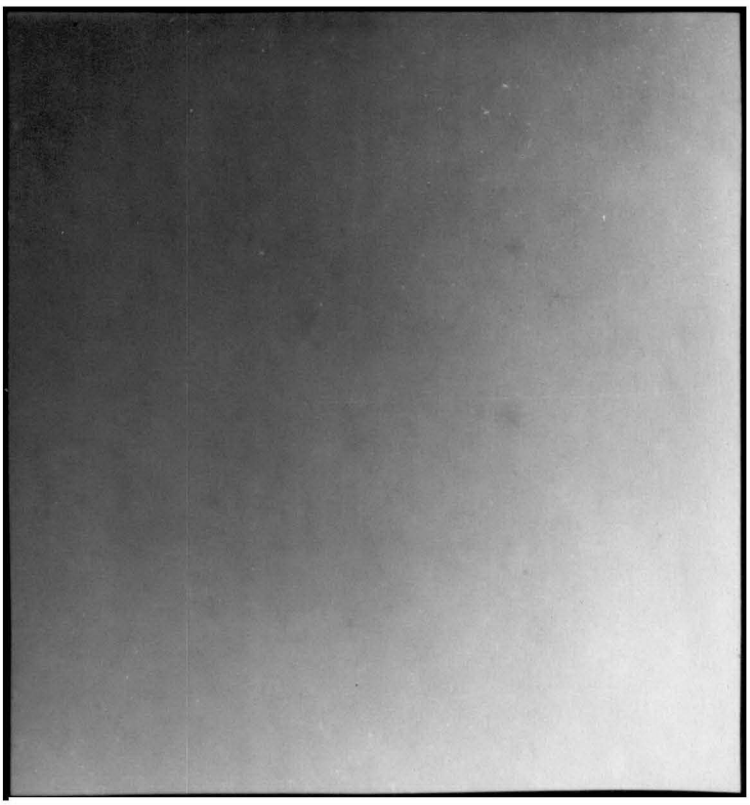


SOURCE OF ILLUMINATION - "PHOTO FLOOD" 250 WATTS - A FILTER, CORNING HR RED, OF A REDDISH AMBER COLOR WAS PLACED IN FRONT OF THE CAMERA LENS. THE SCATTERED LIGHT BECAME LESS INTENSE AND THE DETAILS OF THE PLATE BECAME CLEARER.

PLATE 7

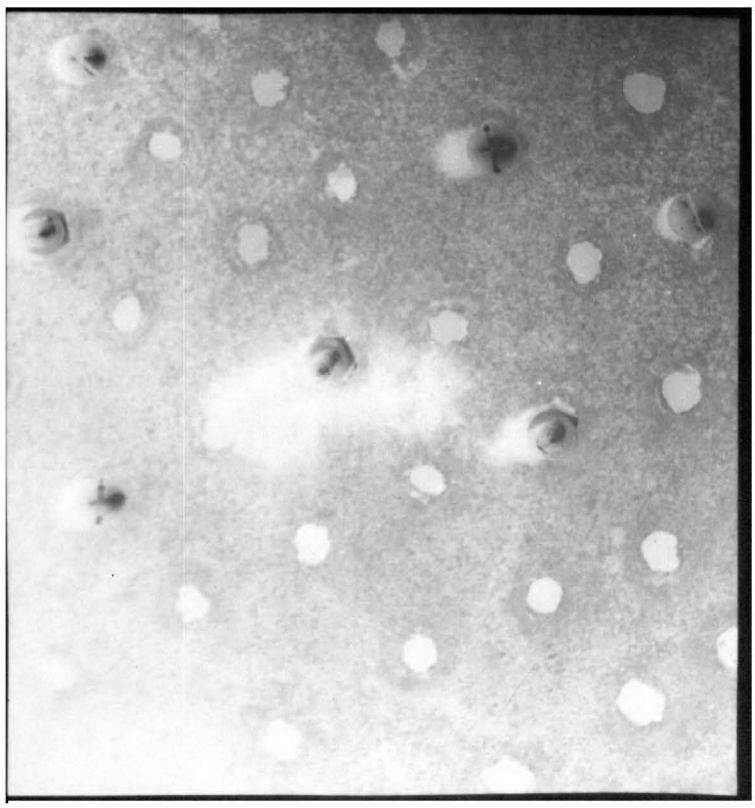
SOURCE OF ILLUMINATION - "PHOTO FLOOD" 250 WATTS - NO FILTER IN THE LIGHT PATH. TO THE EYE THE PLATE WAS SEEN WITH GREAT DIFFICULTY BECAUSE OF THE INTERVENING MASS OF SCATTERED LIGHT.

PLATE 8



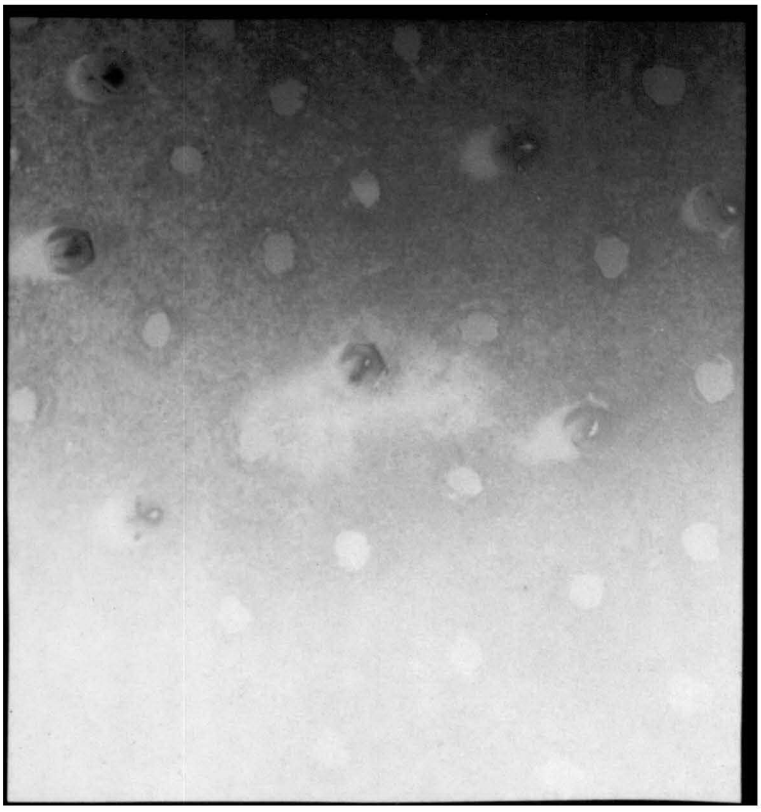
SOURCE OF ILLUMINATION - "PHOTO FLOOD" 250 WATTS - THE CORNING "NOVIAL" SHADE "C" (LEMON YELLOW) FILTER WAS PLACED IN FRONT OF THE DIVING LAMP. TO THE EYE THE MASS OF SCATTERED LIGHT BETWEEN THE EYE AND THE PLATE LARGELY DISAPPEARED.

PLATE 9



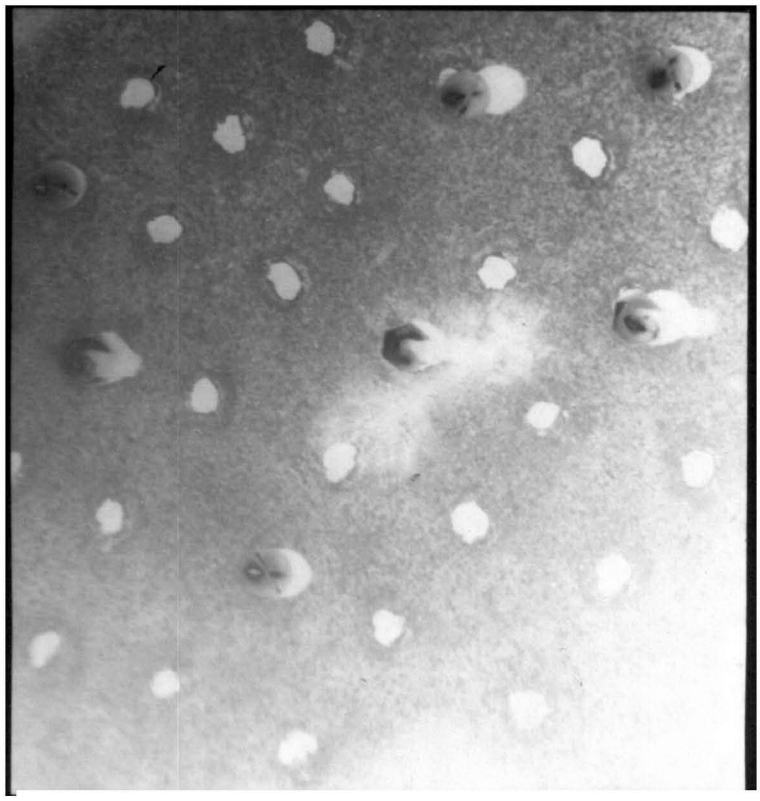
G.E. SODIUM VAPOR LAMP USED AS A SOURCE OF ILLUMINATION - NO FILTER IN LIGHT PATH. TO THE EYE THE PLATE WAS QUITE VISIBLE AND THE DETAILS QUITE CLEAR. THERE DID NOT APPEAR TO BE THE HAZED SCATTERED LIGHT.

PLATE 10



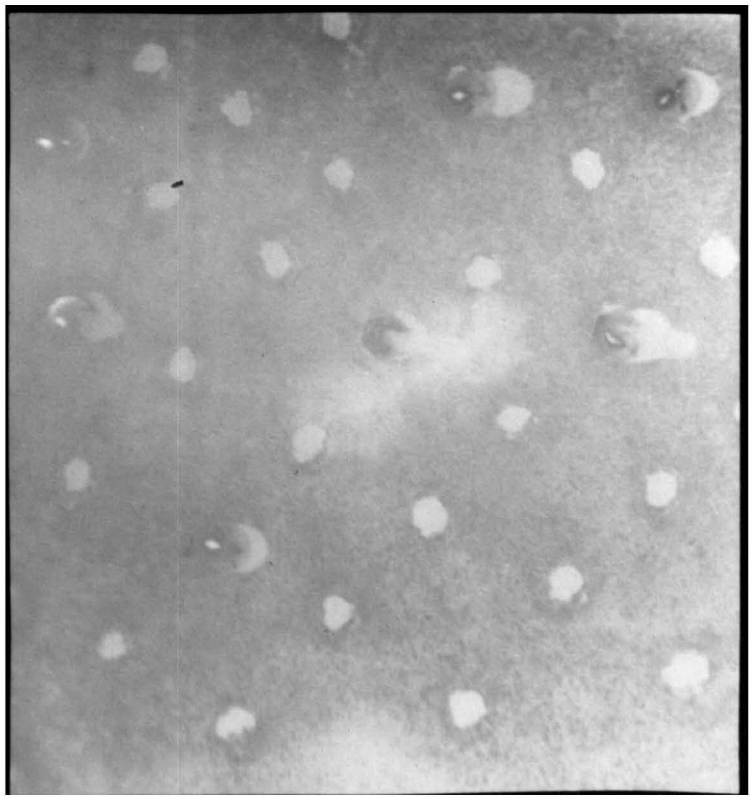
G.E. SODIUM VAPOR LAMPS USED AS A SOURCE OF ILLUMINATION - EASTMAN K-3 FILTER IN FRONT OF CAMERA.

PLATE II



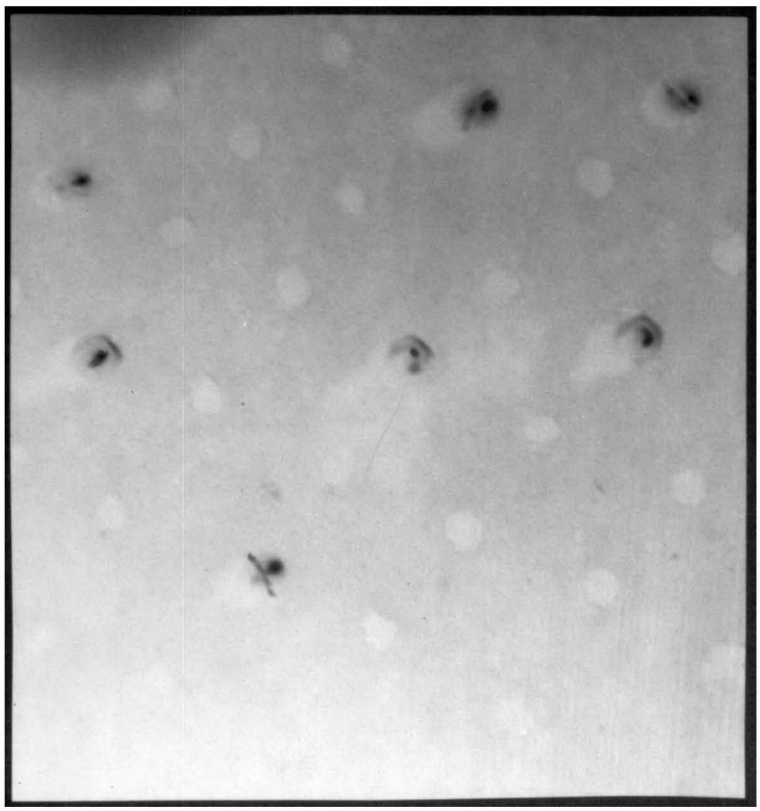
STANDARD DIVING LAMPS USED AS A SOURCE OF IL-LUMINATION - THE CORNING "NOVIAL" SHADE "C" (LEMON YELLOW) FILTER WAS PLACED IN FRONT OF THE DIVING LAMPS. TO THE EYE THE DETAILS OF THE PLATE WERE QUITE DISCERNIBLE.

PLATE 12



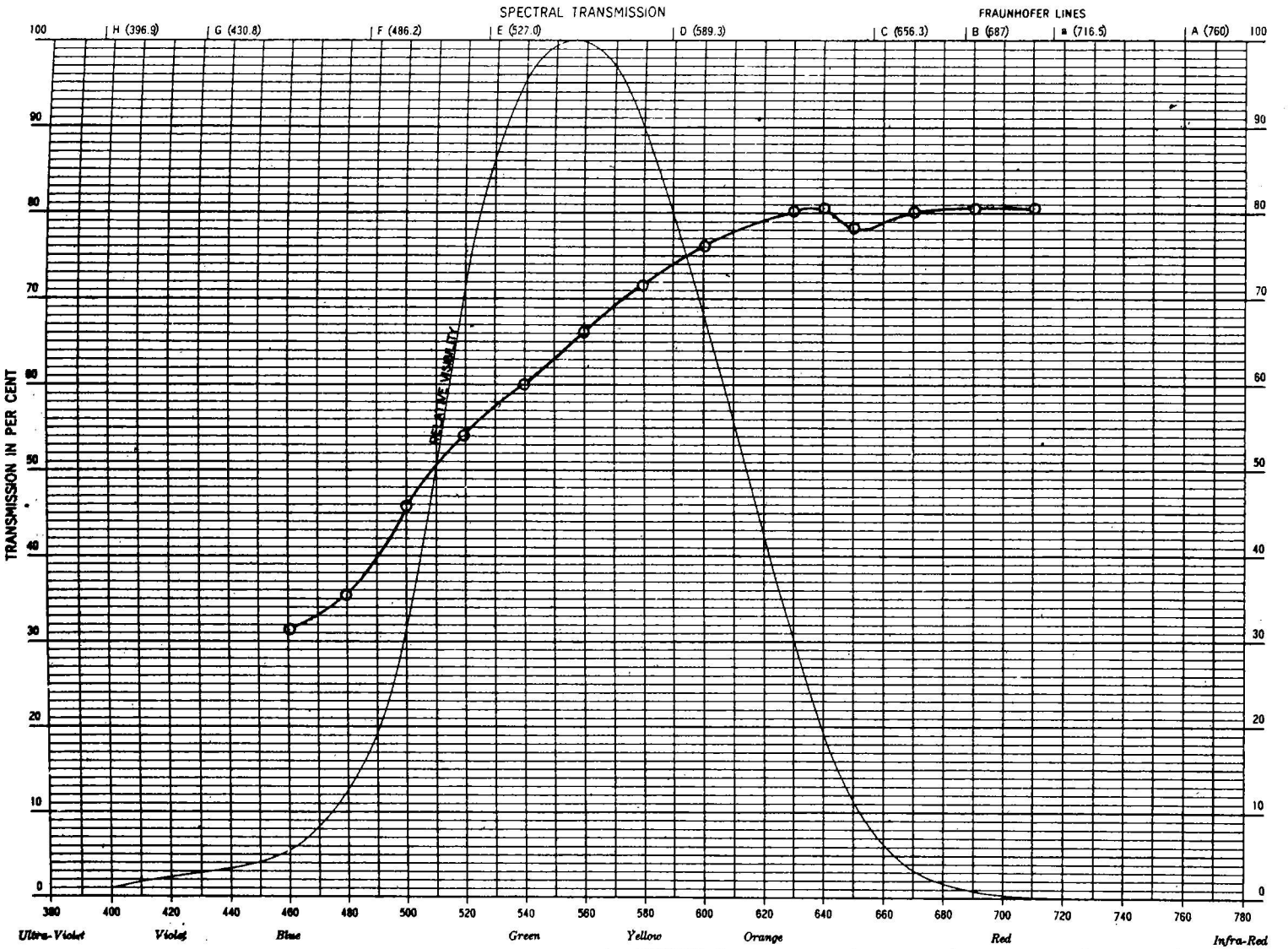
STANDARD DIVING LAMP USED AS A SOURCE OF ILLUMINATION - THE CORNING "NOVIAL" SHADE "C" (LEMON YELLOW) FILTER WAS PLACED IN FRONT OF THE DIVING LAMP. EASTMAN K-3 FILTER WAS PLACED IN FRONT OF THE CAMERA.

PLATE 13



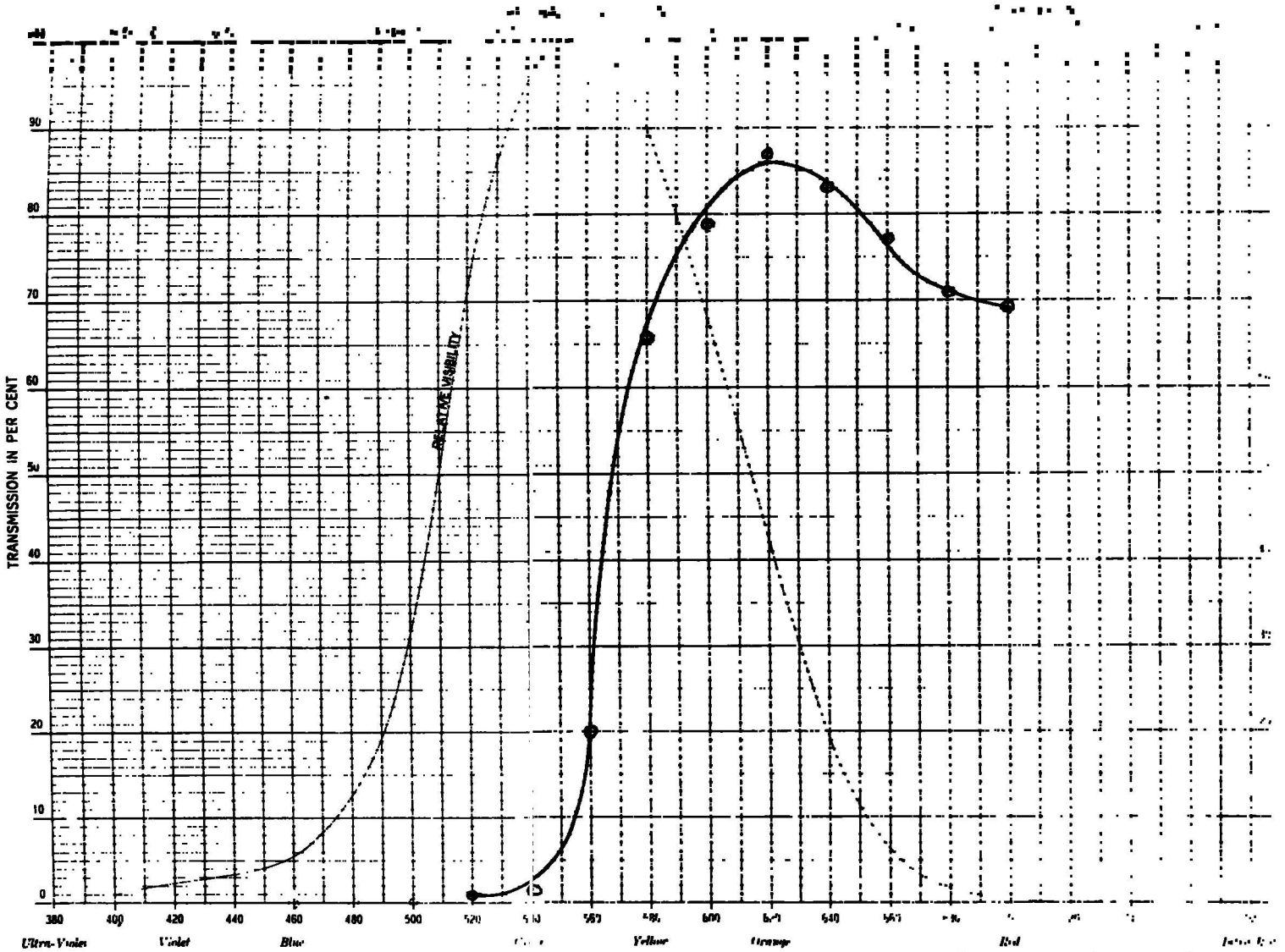
G. E. MERCURY VAPOR LAMPS HIGH INTENSITY WERE USED AS A SOURCE. NO FILTERS IN THE LIGHT PATH. TO THE EYE THE PLATE WAS NOT WELL ILLUMINATED ALTHO THE DETAILS COULD BE DIMLY SEEN.

PLATE 14

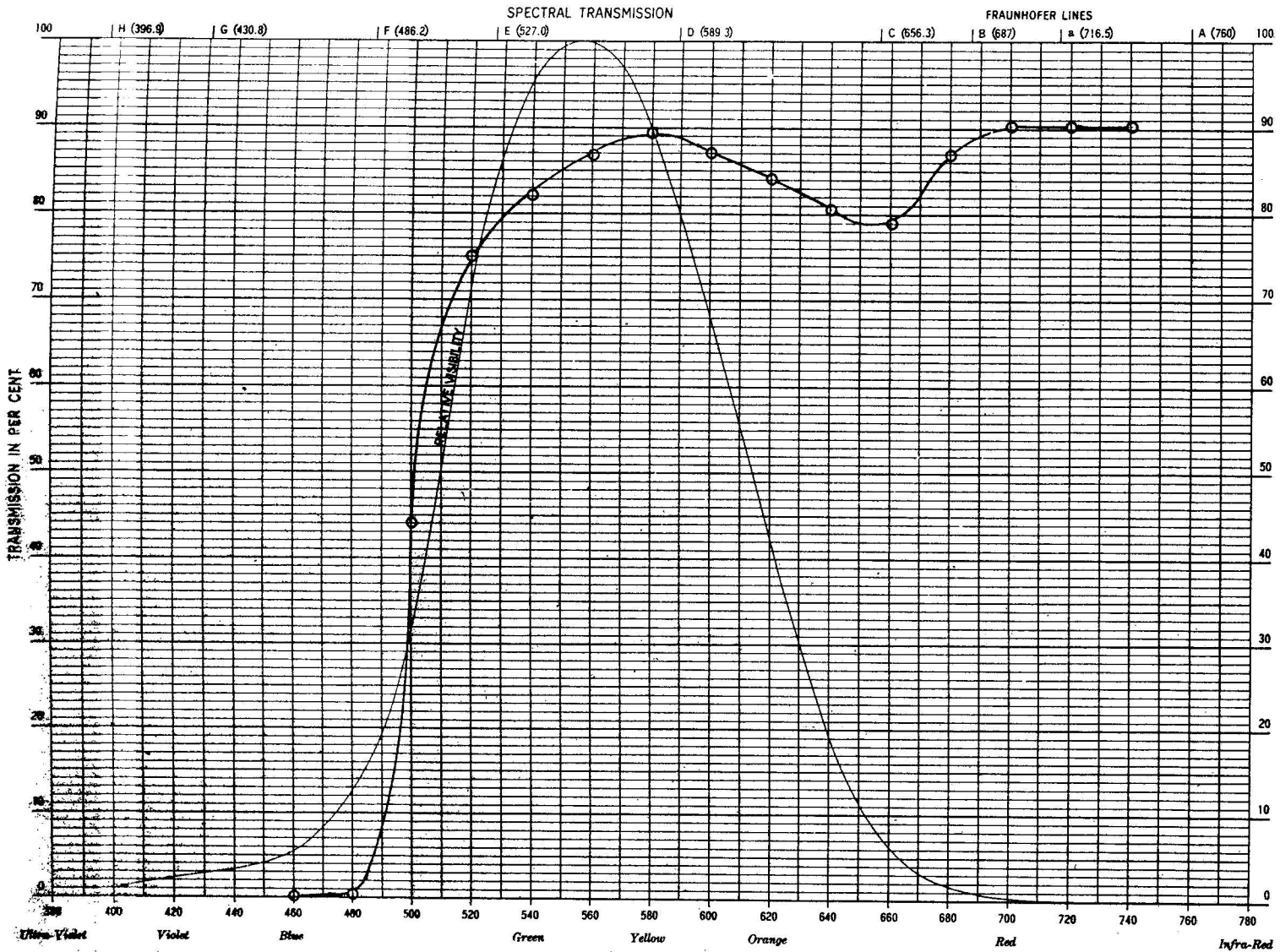


OPTICAL TRANSMISSION OF OPTICAL LAMPS FURNISHED BY CHAS. MORSE & CO.

Plate 15



OPTICAL TRANSMISSION OF CORNING GLASS NO. 246.



OPTICAL TRANSMISSION OF OPTICAL GLASS "NOVIAL" SHADE C

DETERMINATION NO.	METHOD	OBSERVER

PLOTTED BY .....
CHECKED ..... EXAMINED .....

PLATE 17