NAVAL RESEARCH LABORATORY REPORT

GLARE REDUCTION OF
LOW REFLECTION COATINGS
ON
INSTRUMENT WINDOWS

By J. D. Haynsworth

- Report B-2996 -

FR-2996

Approved by:

G.K.C. Hardesty - Asst. Section Head

NAVY DEPARTMENT
OFFICE OF NAVAL RESEARCH
NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

Navy Department - Office of Naval Research

INTERIOR COMMUNICATION SECTION

31 October 1946

GLARE REDUCTION OF LOW REFLECTION COATINGS ON INSTRUMENT WINDOWS

By J. D. Haynsworth

- Report B-2996 -

Approved by:

G.K.C. Hardesty - Asst. Section Head

W. B. Roberts
Section Head

Commodore H.A. Schade, USN
Director, Naval Research Laborato

Preliminary Pages .... a-d
Numbered Pages 6
Plates 22
Distribution List .... d

ABSTRACT

The object of this problem was to investigate the glare reduction properties of low reflection coatings as applied to sample transparent materials for use on instrument windows. External, general, illumination of the instruments was assumed.

The effectiveness of such coatings in reducing glare will depend mainly on the angle of incidence of the reflected glare source and on the freedom of the surface from oil or other deleterious substances.

A suitable anti-glare coating if properly applied will be almost as effective for red or blue light as for white light.

The sample coatings on glass are somewhat fragile in that they can be readily removed by vigorous scouring with common abrasive cleaners such as Bon Ami.

The coated plastic samples are considered unsuitable for instrument windows aboard-ship in that they are easily scratched and clouded by relatively gentle cleaning with common abrasive cleaners such as Bon Ami.

It was concluded that the application of low reflection coatings to instrument windows will under many conditions materially contribute to the legibility of the instruments on which they are installed.

TABLE OF CONTENTS

INTRODUCTION

Authorization

1. This problem was authorized by BuShips ltr. JJ17/Glare P(335) of 10 May 1945 to Dir. NRL.

Object of Investigation

2. The object of this investigation was to investigate the glare reduction properties of low reflection coatings as exhibited by the submitted samples of transparent material intended for use as instrument windows.

Description of Material

3. The samples submitted consisted of three (3) glass discs (one uncoated and two coated), four (4) hexagon-shaped coated glass instrument windows and two (2) coated plastic sheets.

4. The uncoated disc is 9-1/2 inches in diameter and 0.375 inches thick. The coated discs are 9-1/2 inches in diameter, 0.35 inches thick and have central areas 4 inches in diameter coated on both sides. The coated discs were assigned Laboratory identifications "No. 1", and "No. 2" and the uncoated disc, "No. 3".

5. The hexagonal glass instrument windows are approximately 0.115 inch thick, 3-3/4 inches wide by 2-inches high. Of these, the two windows identified by Bureau inscription as "regular" were marked HA and HB. The two identified as "baked" were marked "HC" and "HD" by the Laboratory.

6. The 1/8-inch plastic sheets were identified by Bureau inscription as BT48-360A and Lucite HC201. For these investigations they were identified as "P1" and "P2" respectively.

PROCEDURE

Methods

7. In order to obtain the information requested by the letter of authorization a simple procedure to establish the anti-glare properties and the improvement in visibility attending the use of low reflection coatings as applied to instrument windows was evolved. As determinations of comparative reflection and transmission values of the submitted uncoated and coated samples under like conditions were considered more practical and more pertinent to this problem than the determination of the actual reflection and transmission factors, the investigation was conducted on the comparative basis.

8. In preparation for the tests, the untreated areas of the coated discs were blanked off with velvet-finished black paper. A similar area of the uncoated disc was blanked to insure like test conditions.

9. Each of the glass instrument windows and plastic sheets was mounted on heavy cardboard to facilitate handling. Each was then blanked off with velvet-finished black paper so as to expose an area 2-3/4 inches wide by 1-7/8 inches high.

10. A Weston Model 622 micro-ammeter and General Electric Type 88x565 barrier-layer cells with filters were used for determining light intensity values. For "white" light data (requiring response approximating that of the average human eye) a cell with a Wratten No. 102 compensating filter was employed, while for "red" light a Celanese Lumalith No. 07076 filter and for "blue" light a Corning Pyrex No. 5113 filter were used. For red light measurements (compensated to the human eye) a combination of the above red filter and Wratten compensating filter were used. For compensated blue light measurements both the blue and Wratten compensating filters were used. The light cells were protected from stray light by means of a louvered box.

11. Plate 20 shows the spectral response of the filter-equipped cells as compared with the response of the average human eye. The curves of the cells were computed from spectral analysis of the filters and from manufacturer's data on the cells. The curves for the average human eye are based on "Values of Relative Luminosity" in the "Proceedings of the International Commission on Illumination" of June 12-21, 1939. It should be noted that these relative response scales apply only to individual curves and do not show relationship between the curves.

12. A 300 watt 115 volt projection lamp and a simple condensing lens was employed as a light source for measurements involving the use of a single filter. A Navy 12-inch searchlight with a 12.5 volt 20 ampere aircraft landing lamp was employed when combinations of filters were required and a more intense source was desirable.

13. In making transmission measurements the light source was so trained that the beam would cover the area of the barrier-layer cell and the lamp voltage was so adjusted as to produce a large scale reading on the microammeter. Care was taken to maintain a constant lamp voltage and to compensate for fatigue of the barrier layer cell. The samples were carefully cleaned and interposed one at a time between the cell and the light source so that the microammeter would indicate values of light transmitted through the samples. The samples were then rotated about their vertical axes and readings were obtained for a series of angles of incidence varying from 0 to 65 degrees. The ratios of these readings to the values obtained for the beam reading were taken as comparative transmission factors for the several angles.

14. In determining the reflection factors or glare properties, a sample was centered in the light beam and the light cell was arranged so as to intercept the reflected light. The voltage of the light source was adjusted so as to produce a convenient scale reading on the micro-ammeter for a coated sample. The samples were rotated about their vertical axes and readings were taken for a series of angles of incidence varying

from 10 to 65 degrees, after the cell had been repositioned in each case to meet the requirement that it be placed in the center of the reflected beam. In calculating the reflection of the sample at each angle, the microammeter reading of the unobstructed beam was taken as 100 percent.

15. The set-up for determining comparative transmission and reflection is shown on Plate 19.

16. After the above tests, the effect of oil and abrasives on the coatings were investigated. For this purpose, one of the coated glass discs, one of the regular hexagons, and one of the baked hexagons was used.

17. An angle of incidence of 40 degrees was chosen to compare the samples before and after these tests. Percentages of reflection and transmission were recorded at 40 degrees angle of incidence using compensating filters and the photoelectric cells. With the set-up arranged for transmission measurements the sample was carefully removed so as not to disturb the photoelectric cell or its relationship with the light beam. Step 1: The sample was smeared on both sides with a thick coating of penetrating oil, then wiped with absorbent cotton and the percentage of light transmission was recorded. Step 2: The oiled surfaces were cleaned with "Windex" and the percentage of transmission recorded. Step 3: The sample was vigorously scoured for about 3 minutes with a thin mixture of "Windex" and "Bon Ami" and the percentage of transmission was again recorded. After this final step the percentage of reflection was determined by the methods of paragraph 14 and recorded. The reflectance value was not obtained after each step.

18. The hexagon glass and pieces of the plastics were mounted in dummy switchboard type meters which were visually examined under glare conditions. General illumination was furnished by variable intensity overhead incandescent fixtures and a forty (40) watt "daylight" fluorescent lamp was so arranged that its image was reflected by the samples. It was observed that for any angle of incidence the "glare" or visual interference from the image of the fluorescent lamp could be substantially reduced by increasing the level of the general illumination and could be intensified by reducing the general illumination. For comparative observations and for photographs the general illumination was so adjusted that at a 10 degree angle of incidence the reflection of the fluorescent lamp on the untreated samples "just barely" obscured the figures on the meter dials. The glass discs were examined under similar conditions. Plates 11 to 18 inclusive are photographs of the glasses and plastics under glare conditions for angles of incidence of approximately 10 degrees and 65 degrees.

Results

19. The results of the investigations are given as Plates 1 to 10 inclusive and Plate 21.

Discussion

20. The glass discs had apparently been carefully finished, the surfaces were approximate planes and little difficulty was experienced in obtaining consistent readings. Surfaces of the two plastic sheets were comparatively irregular and the resultant distortion of the transmitted and reflected beams caused rather inconsistent readings. However, the curves shown herein are based on the averages of a number of readings for each condition and these results are considered to be representative for the samples submitted.

21. A spectral transmission analysis of sample P1 showed that this plastic had a decided "cut-off" below 450 millimicrons. As this "cut-off" is well within the range of the cells with blue filters the comparatively low transmission as determined with blue filters (see Plates 6 and 9) is attributed to the above "cut-off" effect.

22. It may be noted that on some curves for the hexagons, the sum of the values for transmission and reflection exceeds 100 percent. An examination of the hexagon glasses revealed that these glasses had been so polished as to produce slightly convex surfaces thus making each glass a low power condensing lens. The greater portion of these inconsistencies is attributed to the lens effect of these glasses. Experimental errors, while undetermined are believed to be small.

23. It was observed that oil films tend to neutralize the glare reducing properties of the low-reflection coatings (as is predictable on a theoretical basis) but that these properties can be restored by careful cleanings (removal of the oil). However, the coatings can be permanently damaged by the use of common abrasive cleaners such as Bon Ami.

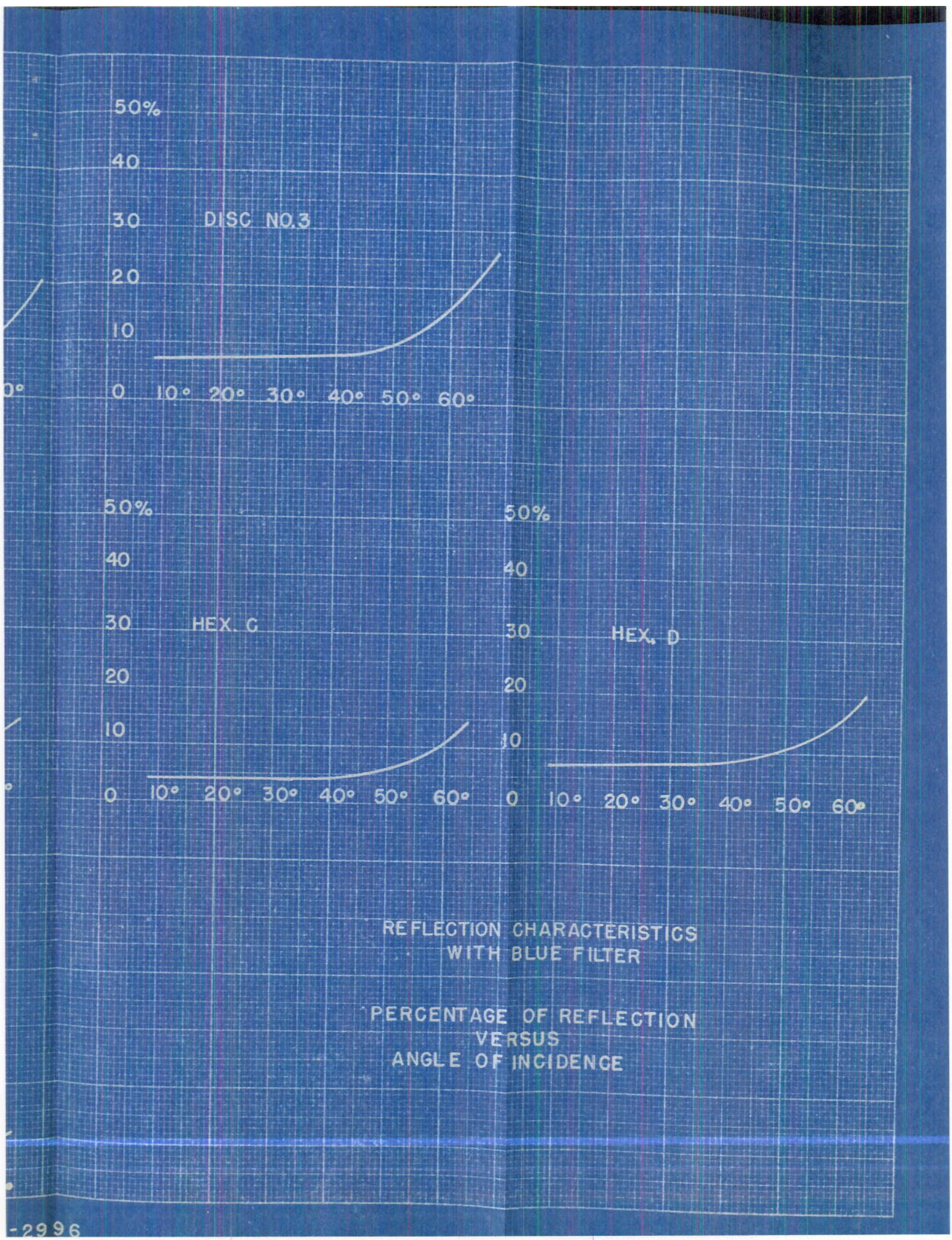
24. After glass disc No. 1 has been scoured with Bon Ami it appeared mottled and scratched as though the coating had been attacked but not entirely removed. A second scouring with Bon Ami for another 3 minutes did not appreciably change its appearance.

25. When the hexagonal samples were scoured once, the coating appeared to be completely removed except for traces on the edges where a mottled surface was observed. More evident traces of the coating remained on the edges of the baked sample HC than on that of the regular sample HA. It appeared that the "baked" sample was slightly more resistant to abrasion than the one marked "regular" but this may have been a result of an uneven amount of scouring of the two samples.

26. An attempt to clean the plastic samples prior to the contemplated oil and abrasion test revealed that these samples were easily damaged. When subjected to abrasion, the surfaces behaved as though they were comparatively soft although this was more probably due to a poor bond to the plastic. A thin application of "Bon Ami" and relatively gentle removal with absorbent cotton, scratched and clouded the surfaces of these samples, hence the submission of the plastics to the oil and abrasion test procedure was not considered warranted.

33. By NRL Test Report No. 593 of 25 February 1946 to BuShips the Laboratory forwarded preliminary information on this problem. The information contained therein is superseded by this report.

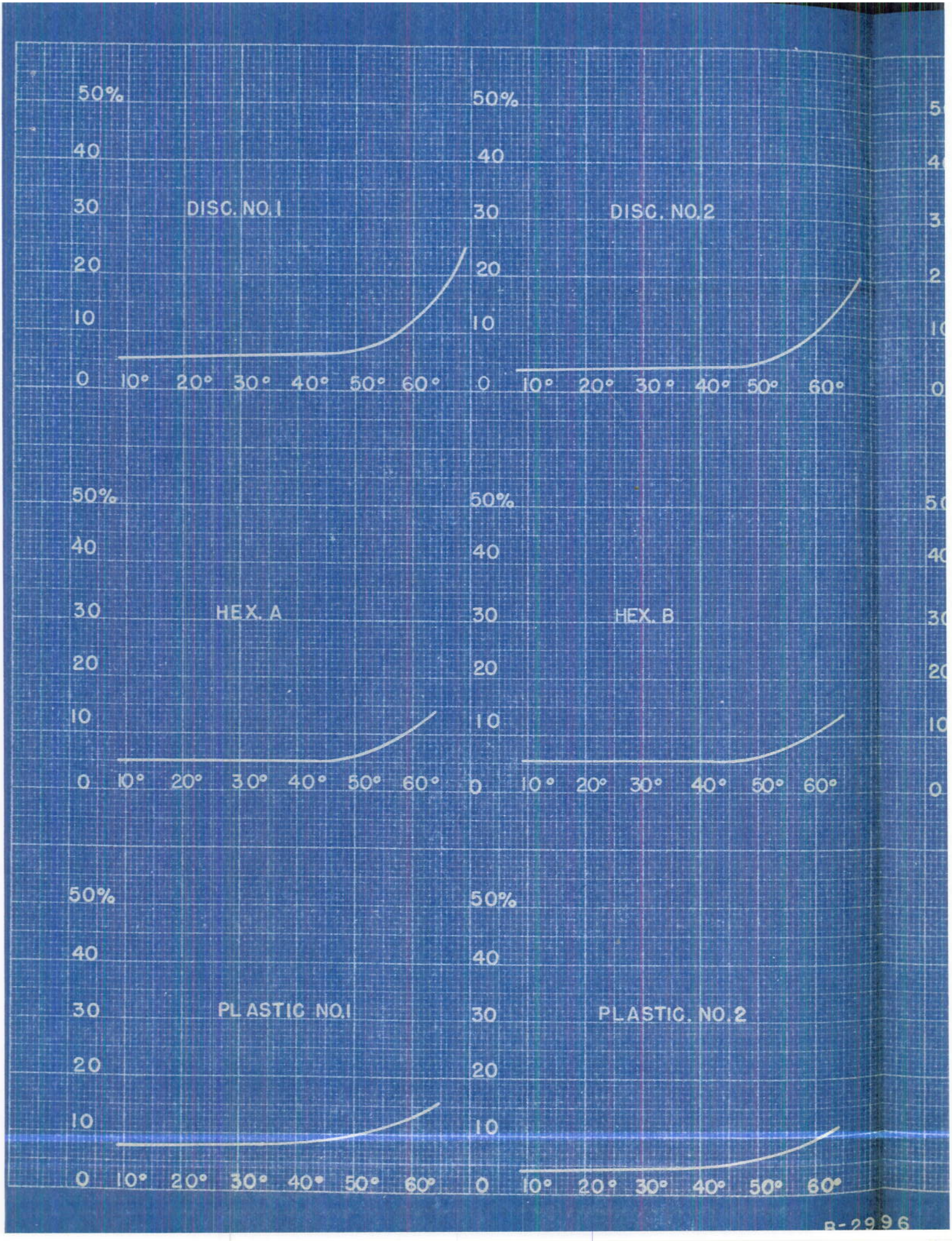
34. Unless otherwise notified within fourteen (14) days from date, this problem (IC-1045) will be considered closed. The samples will be returned to Bureau of Ships, Attn: Code 330.

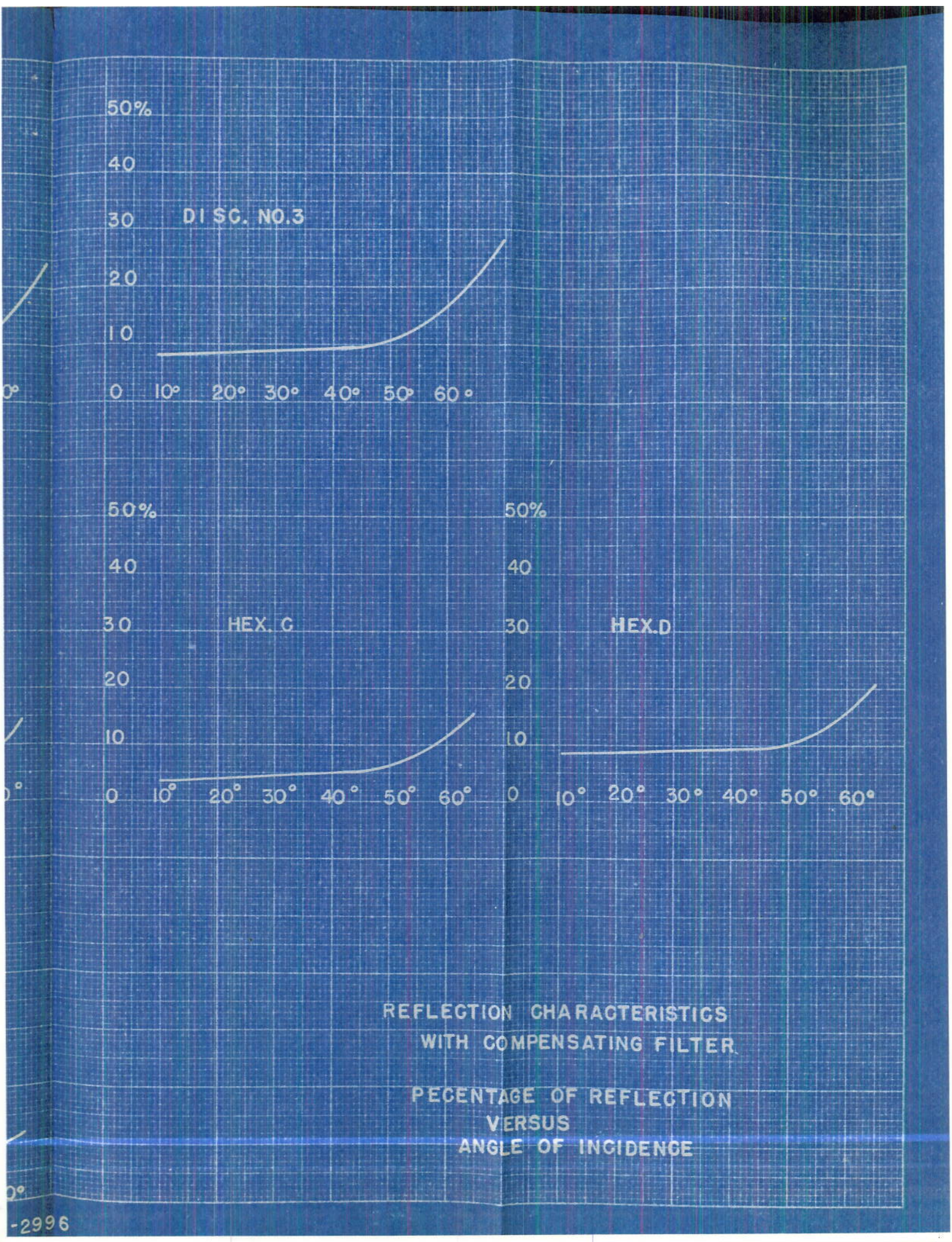


REFLECTION CHARACTERISTICS
WITH BLUE FILTER

PERCENTAGE OF REFLECTION
VERSUS
ANGLE OF INCIDENCE

-2996

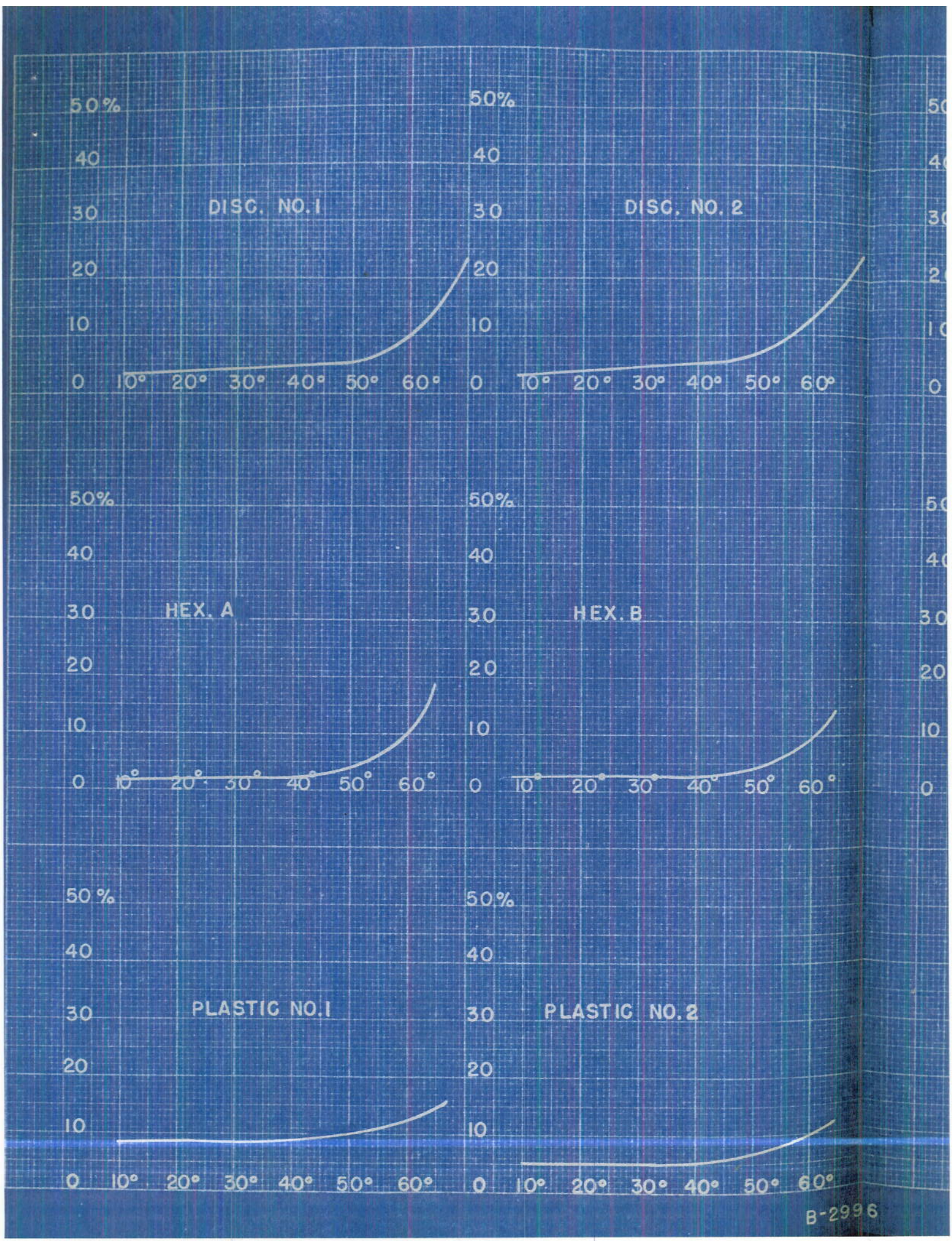

50%
40
30
20
10
0
10°
20°
30°
40°
50°
60°
DISC. NO. 1
DISC. NO. 2
HEX. A
HEX. B
PLASTIC NO. 1
PLASTIC. NO. 2



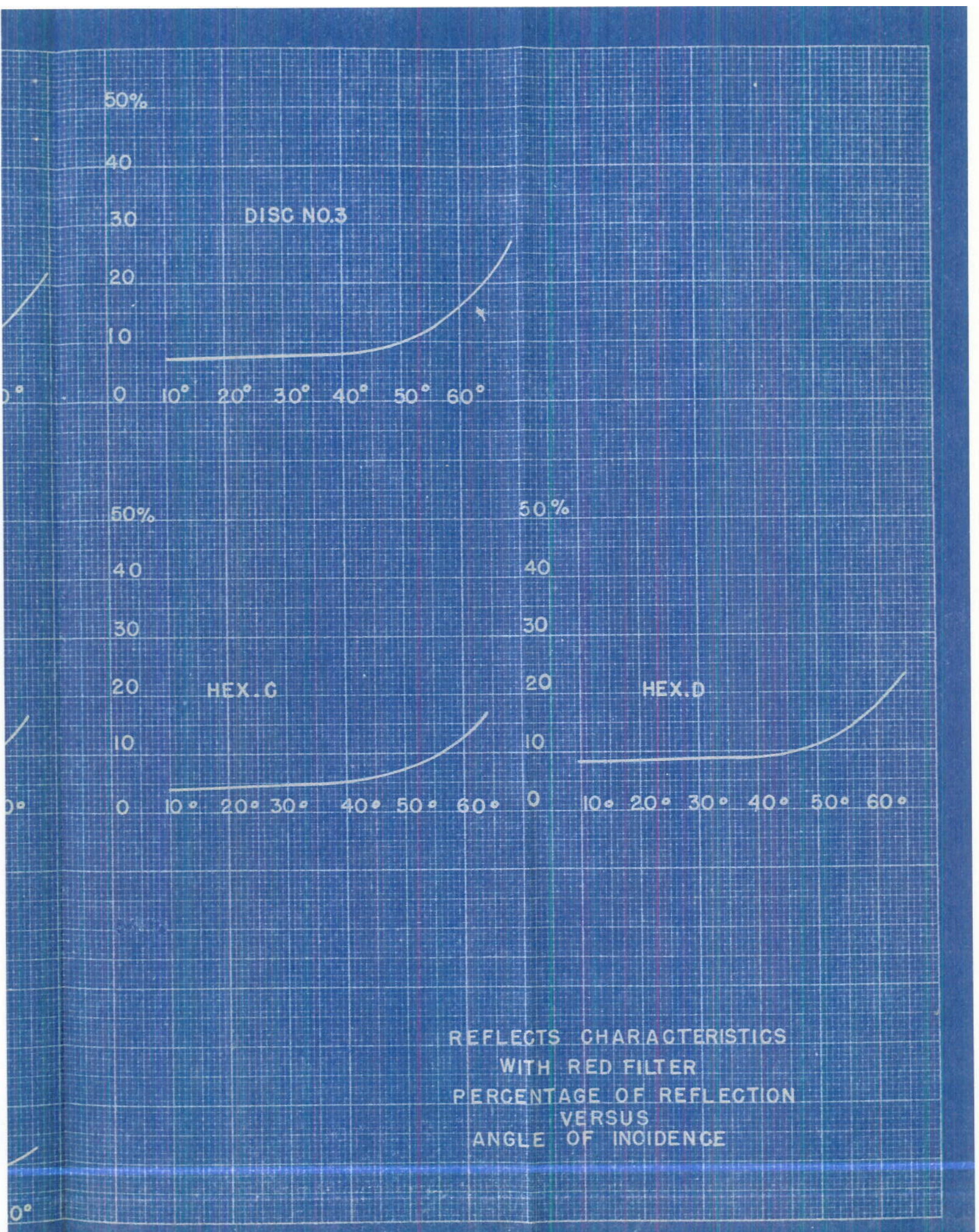
REFLECTION CHARACTERISTICS
WITH COMPENSATING FILTER

PECENTAGE OF REFLECTION
VERSUS
ANGLE OF INCIDENCE

-2996


50%
40
30
20
10
0
10°
20°
30°
40°
50°
60°
DISC. NO. 1
DISC. NO. 2
HEX. A
HEX. B
PLASTIC NO. 1
PLASTIC NO. 2

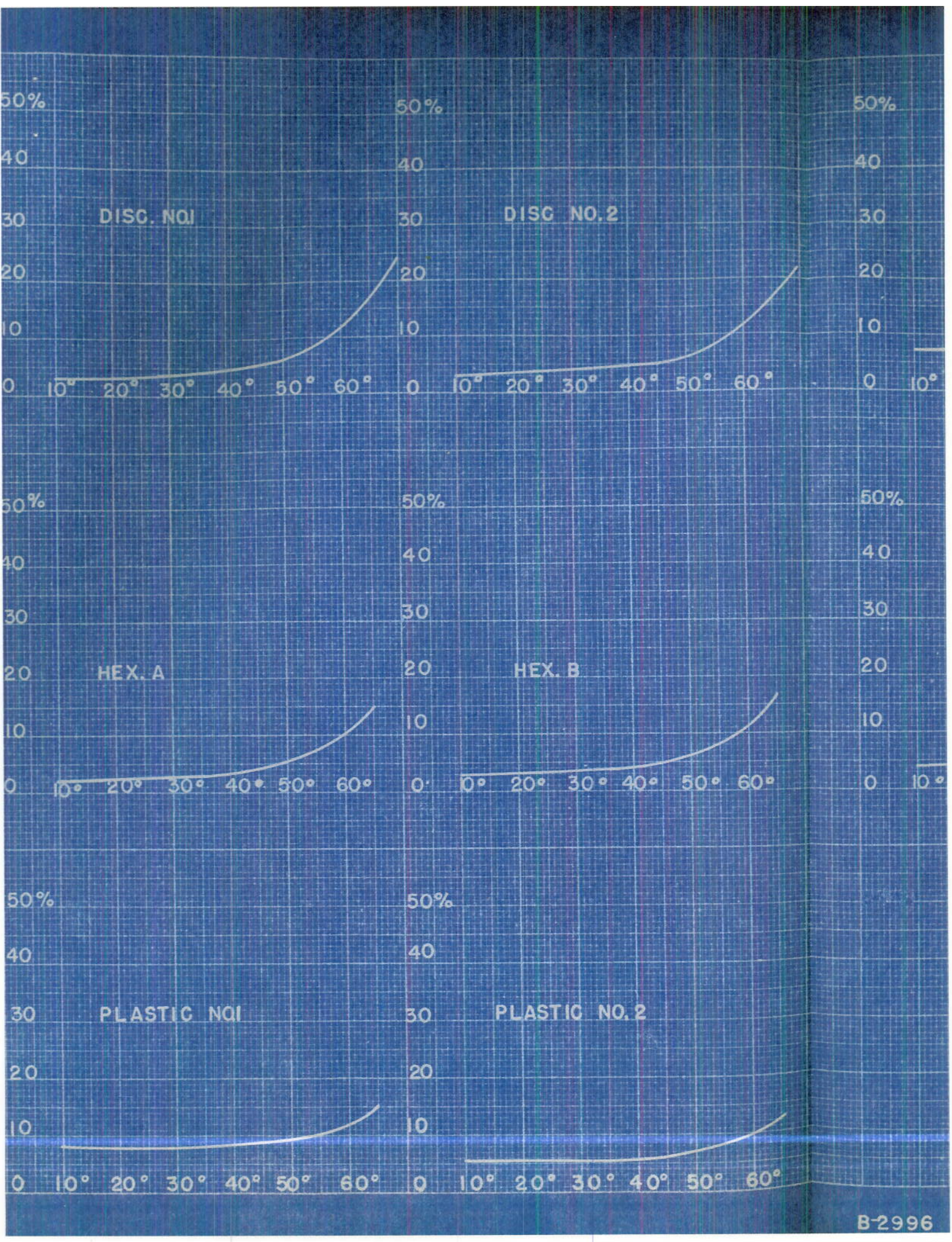
B-2996



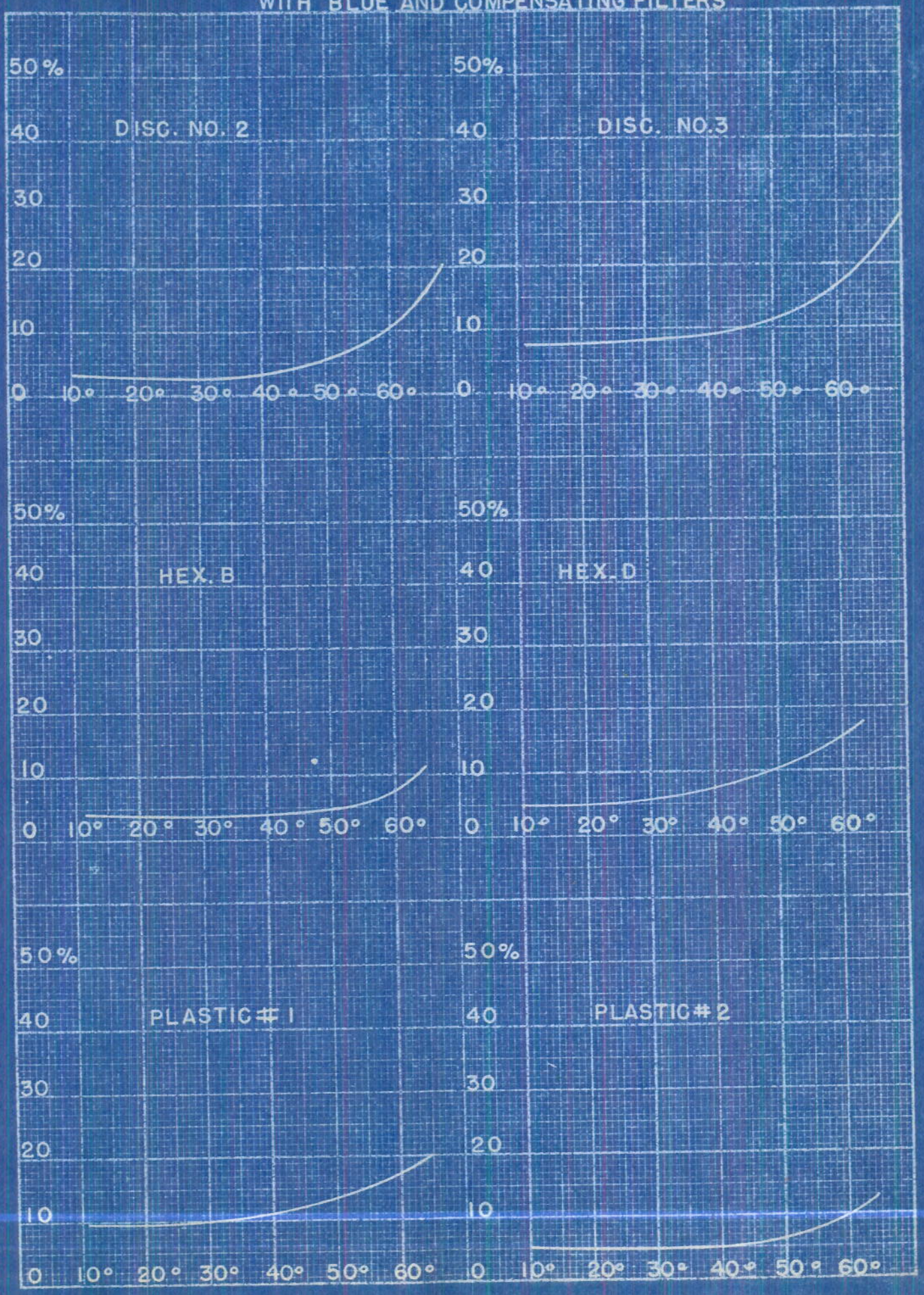
REFLECTS CHARACTERISTICS
WITH RED FILTER
PERCENTAGE OF REFLECTION
VERSUS
ANGLE OF INCIDENCE

B-2996

PLATE 3


50%
40
30
20
10
0
10°
20°
30°
40°
50°
60°
DISC. NO.1
DISC NO. 2
HEX. A
HEX. B
PLASTIC NO.1
PLASTIC NO. 2
B-2996

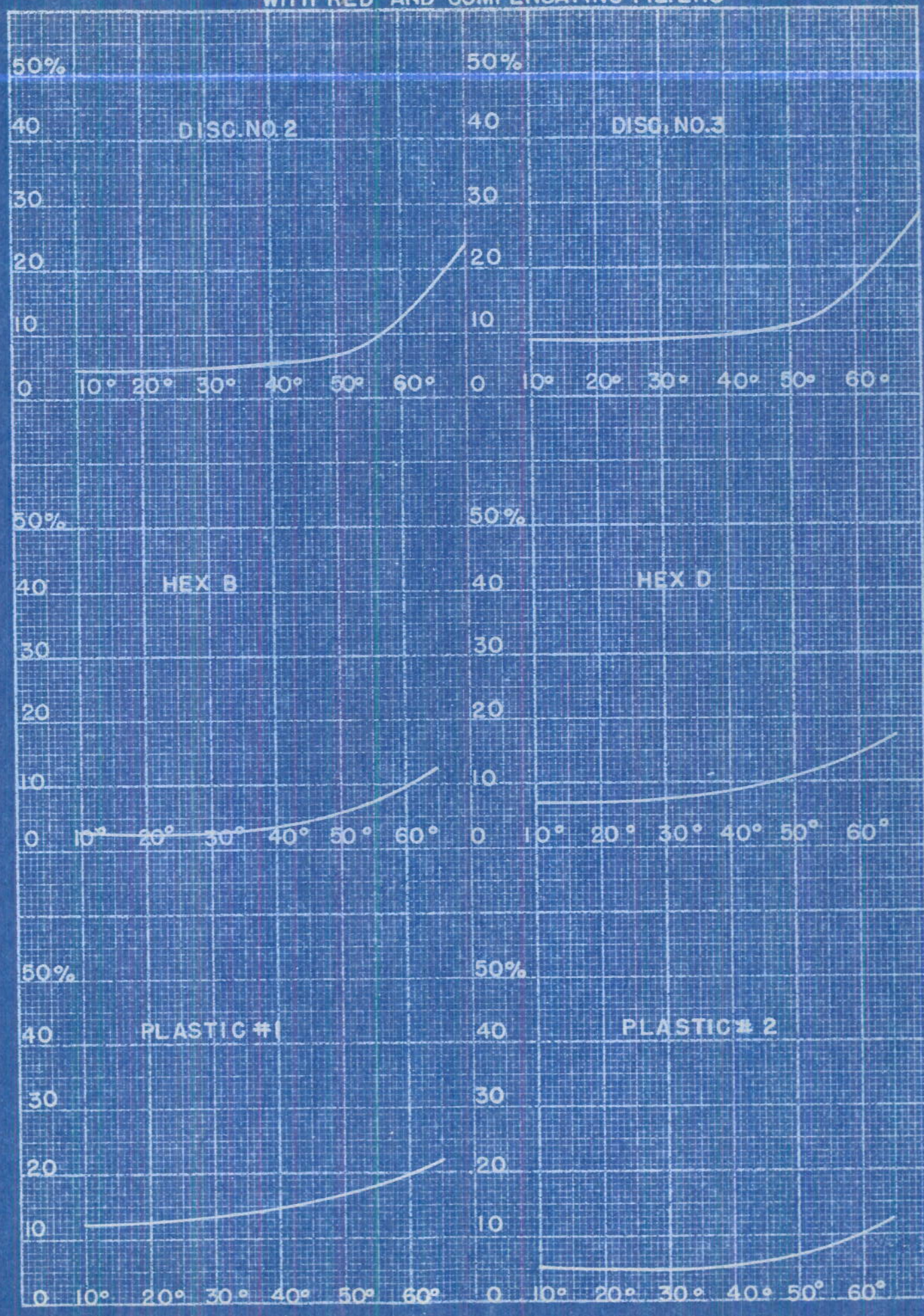
REFLECTION CHARACTERISTICS
WITH BLUE AND COMPENSATING FILTERS



P- 2896

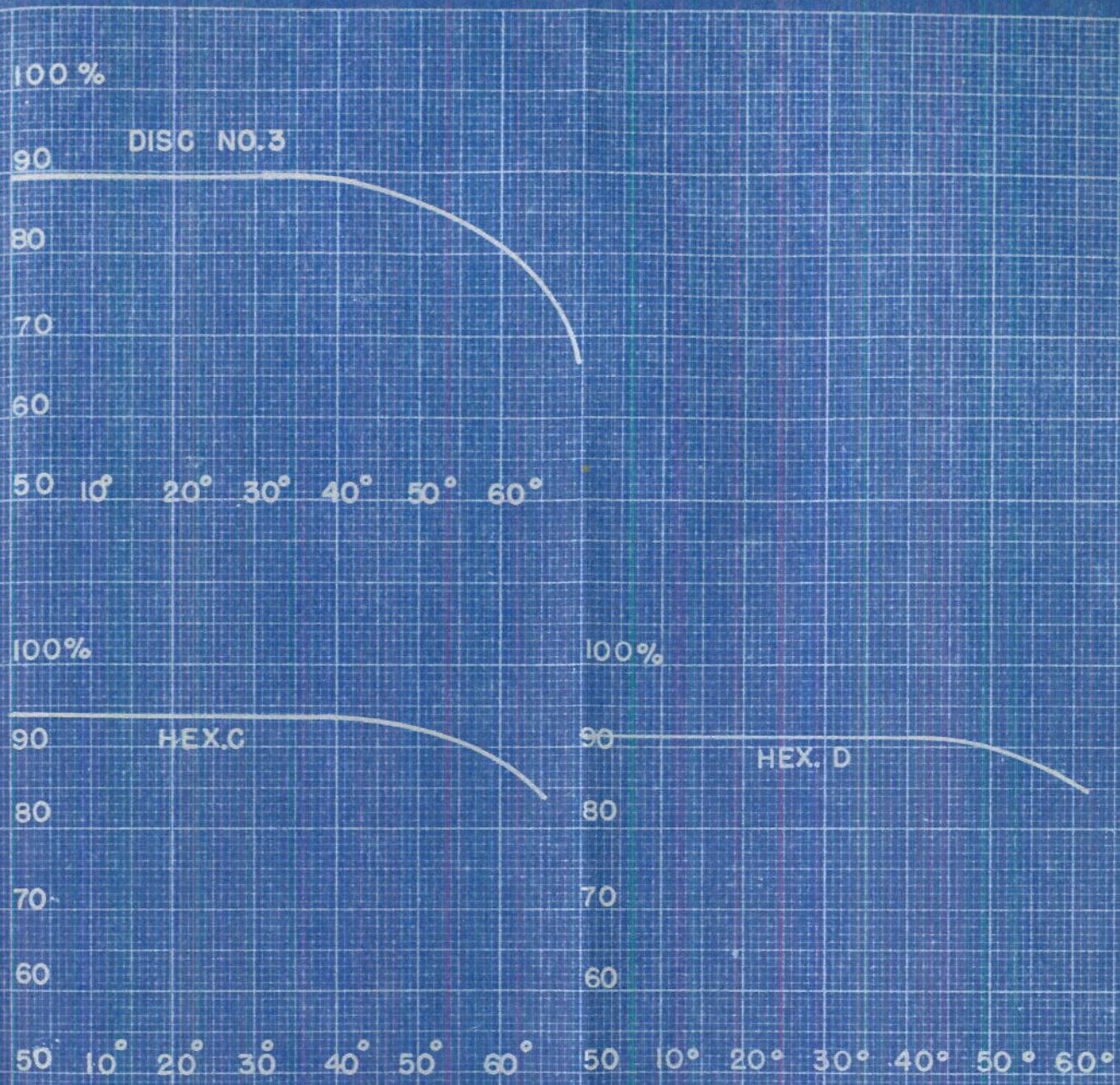
PLATE 4

REFLECTION CHARACTERISTICS
WITH RED AND COMPENSATING FILTERS



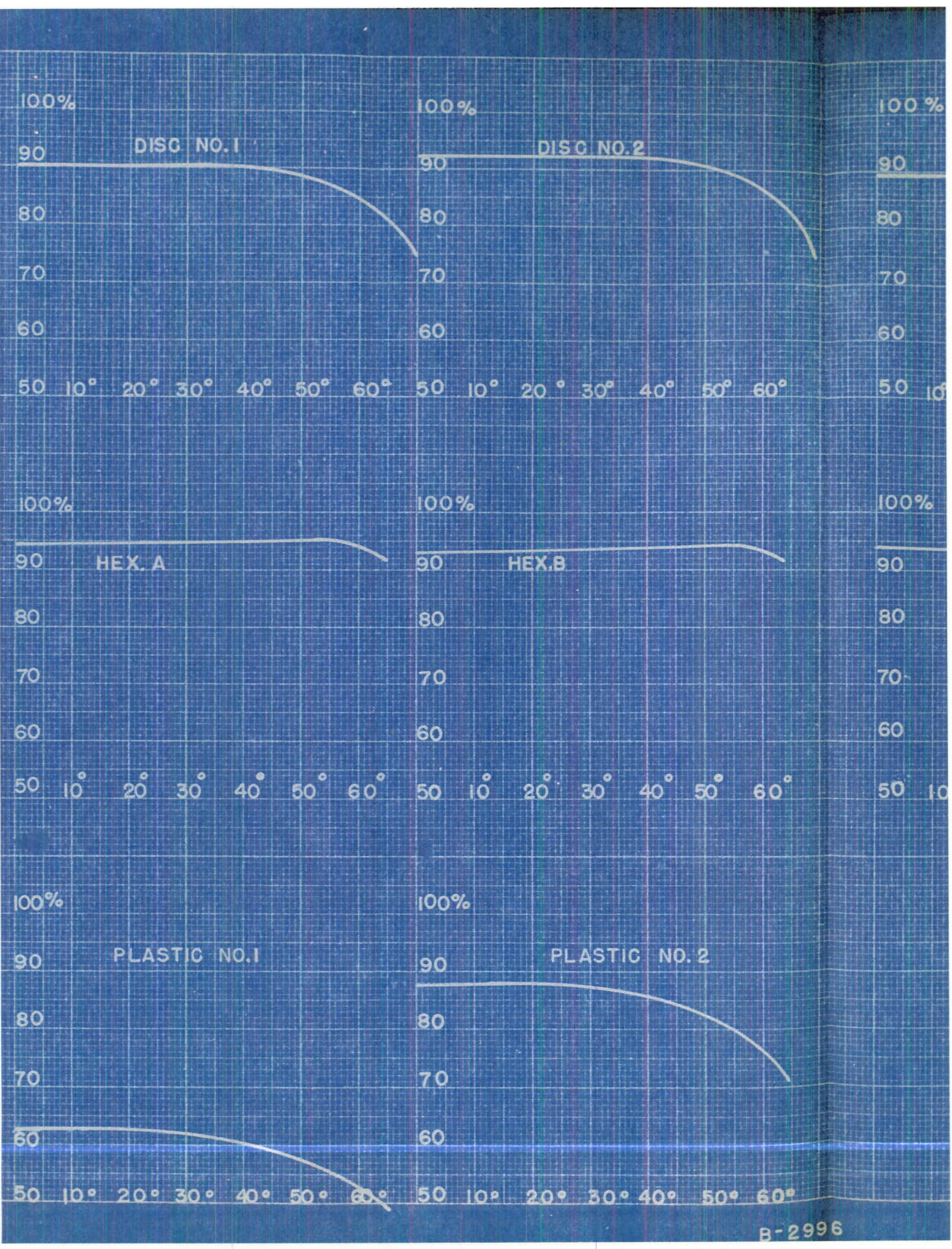
B-2996

PLATE 5

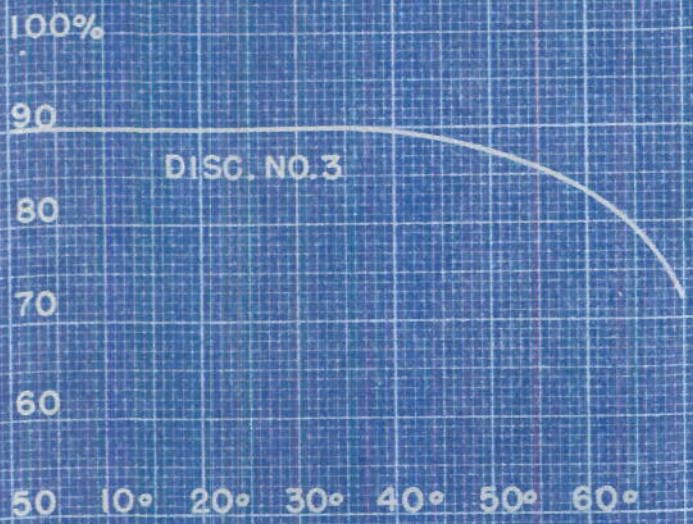


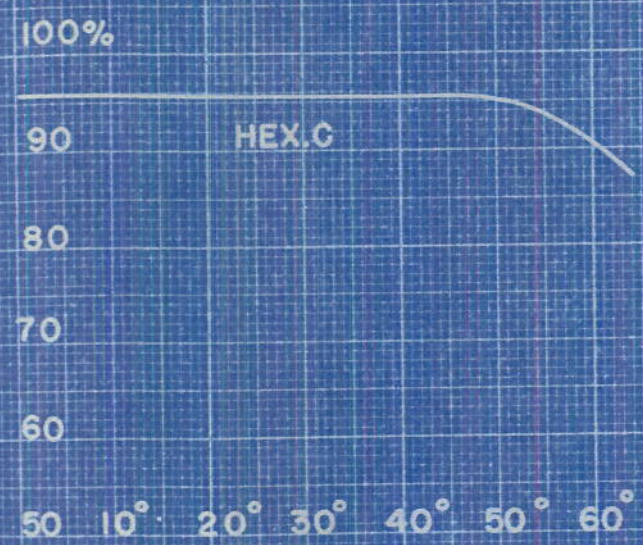
TRANSMISSION CHARACTERISTICS
WITH BLUE FILTER

PERCENTAGE OF TRANSMISSION
VERSUS
ANGLE OF INCIDENCE


100%
90
80
70
60
50
10°
20°
30°
40°
50°
60°
DISC NO. 1
DISC NO. 2
HEX. A
HEX. B
PLASTIC NO. 1
PLASTIC NO. 2

B-2996



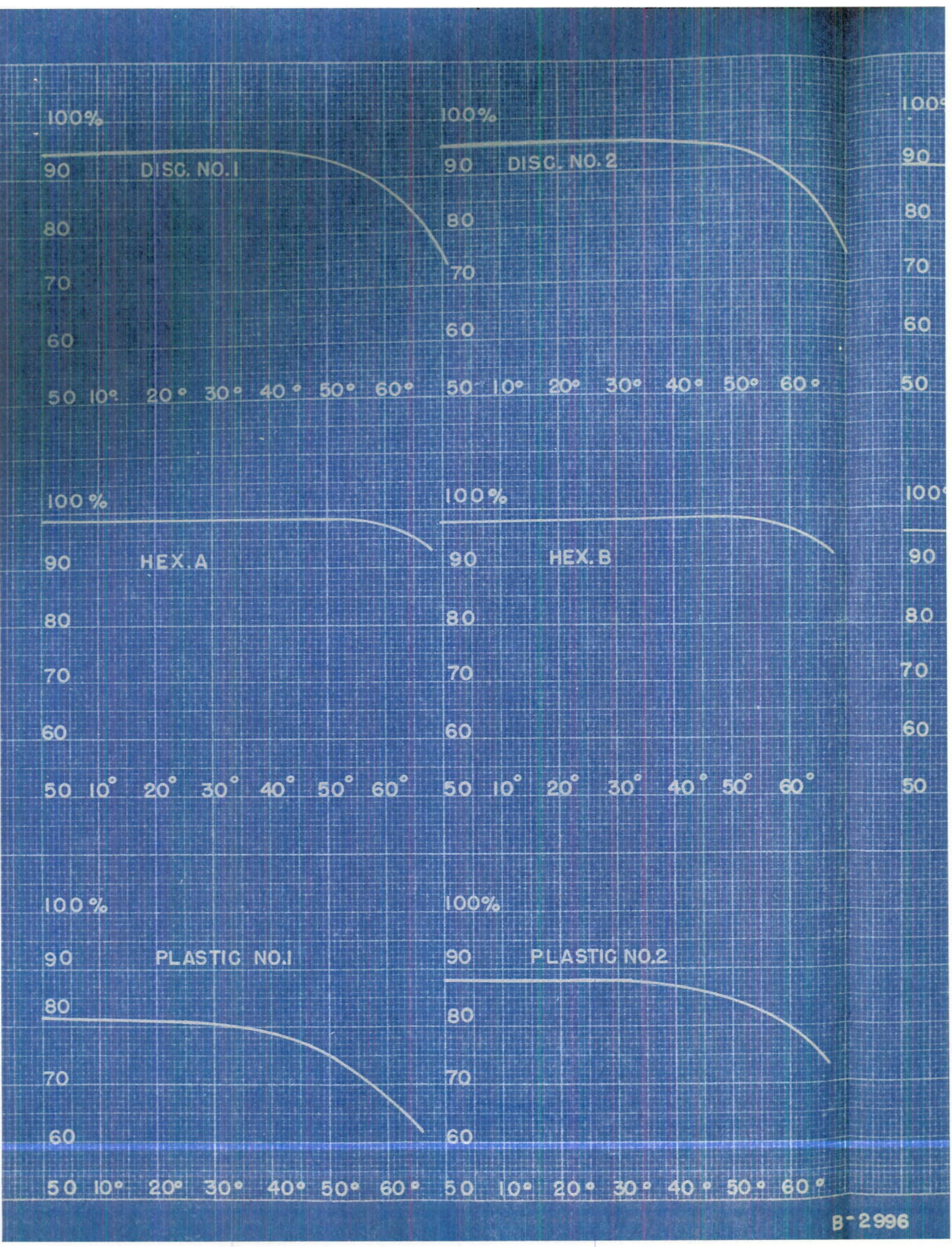


TRANSMISSION CHARACTERISTICS
WITH COMPENSATING FILTER

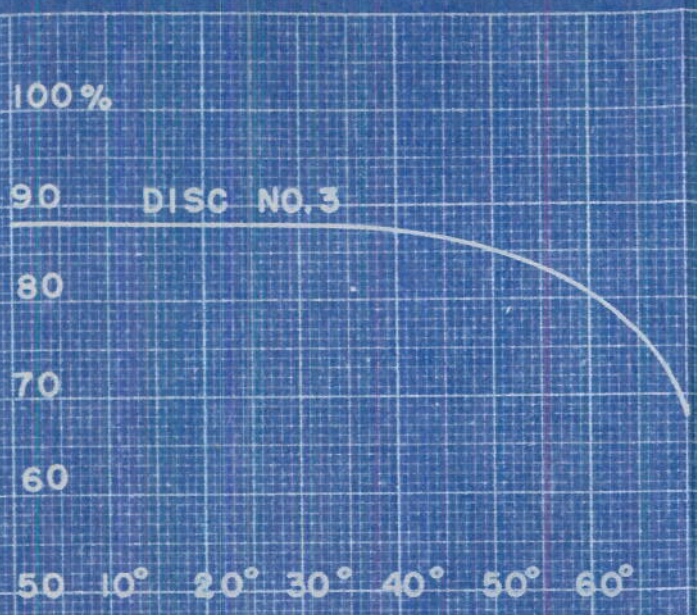
PERCENTAGE OF TRANSMISSION
VERSUS
ANGLE OF INCIDENCE

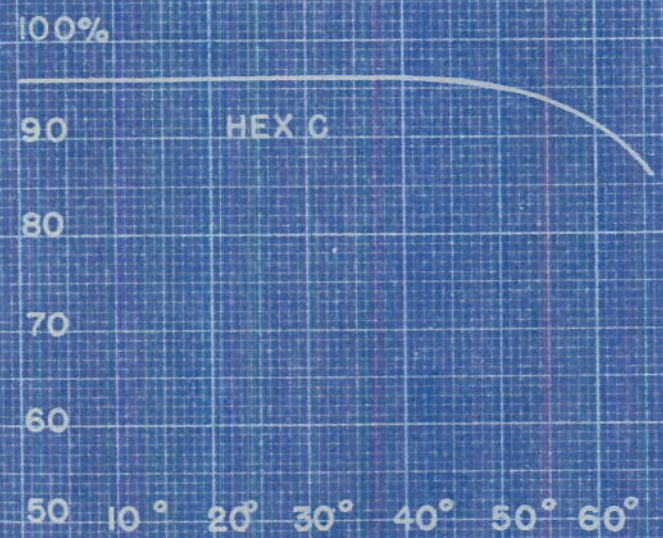
B-2996

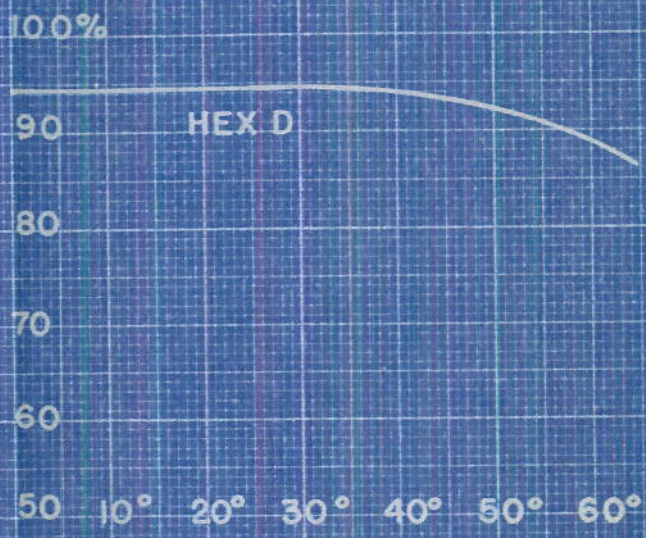
PLATE 7


100%
90
80
70
60
50 10° 20° 30° 40° 50° 60°
DISC. NO. 1
DISC. NO. 2
HEX. A
HEX. B
PLASTIC NO. 1
PLASTIC NO. 2

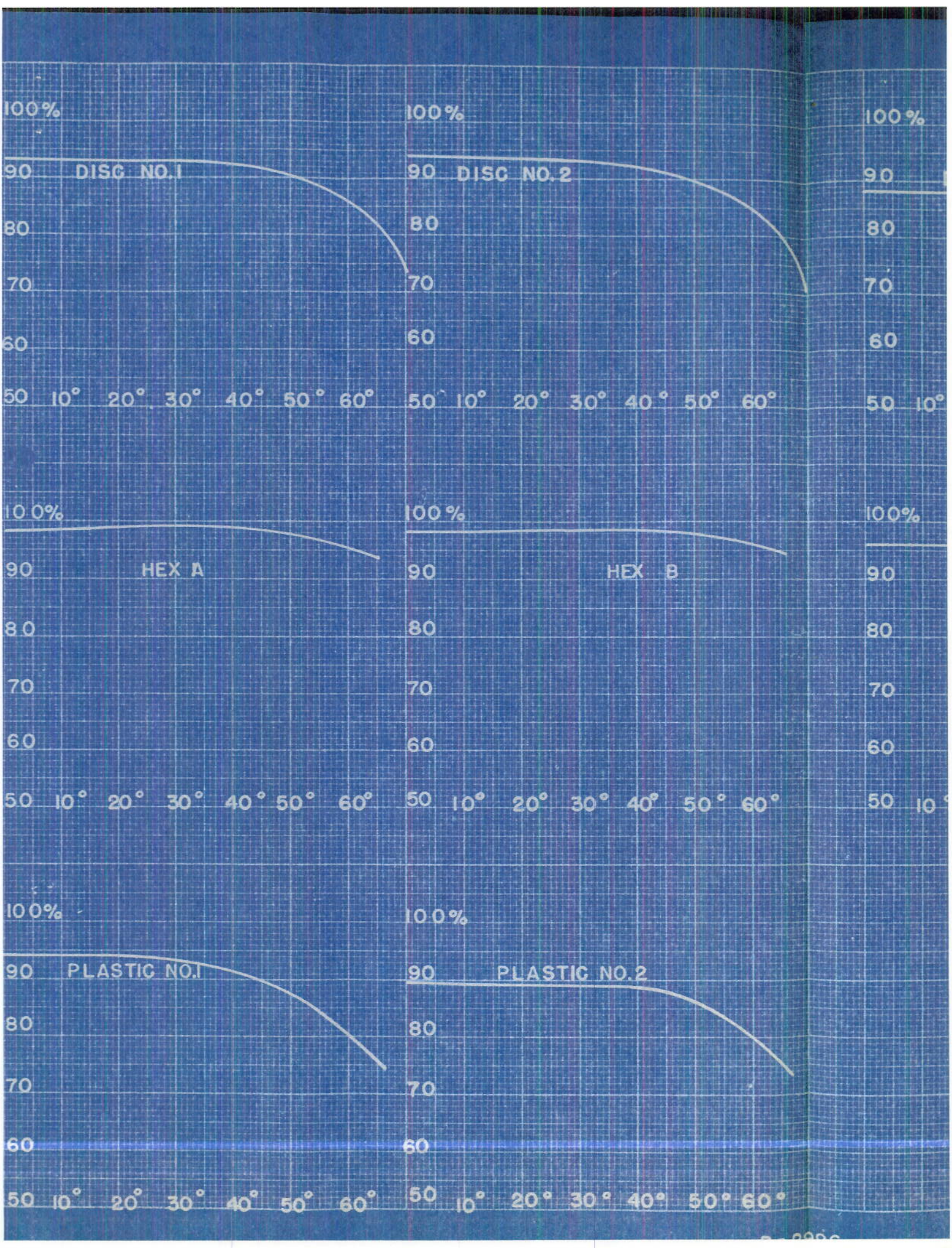
B-2996



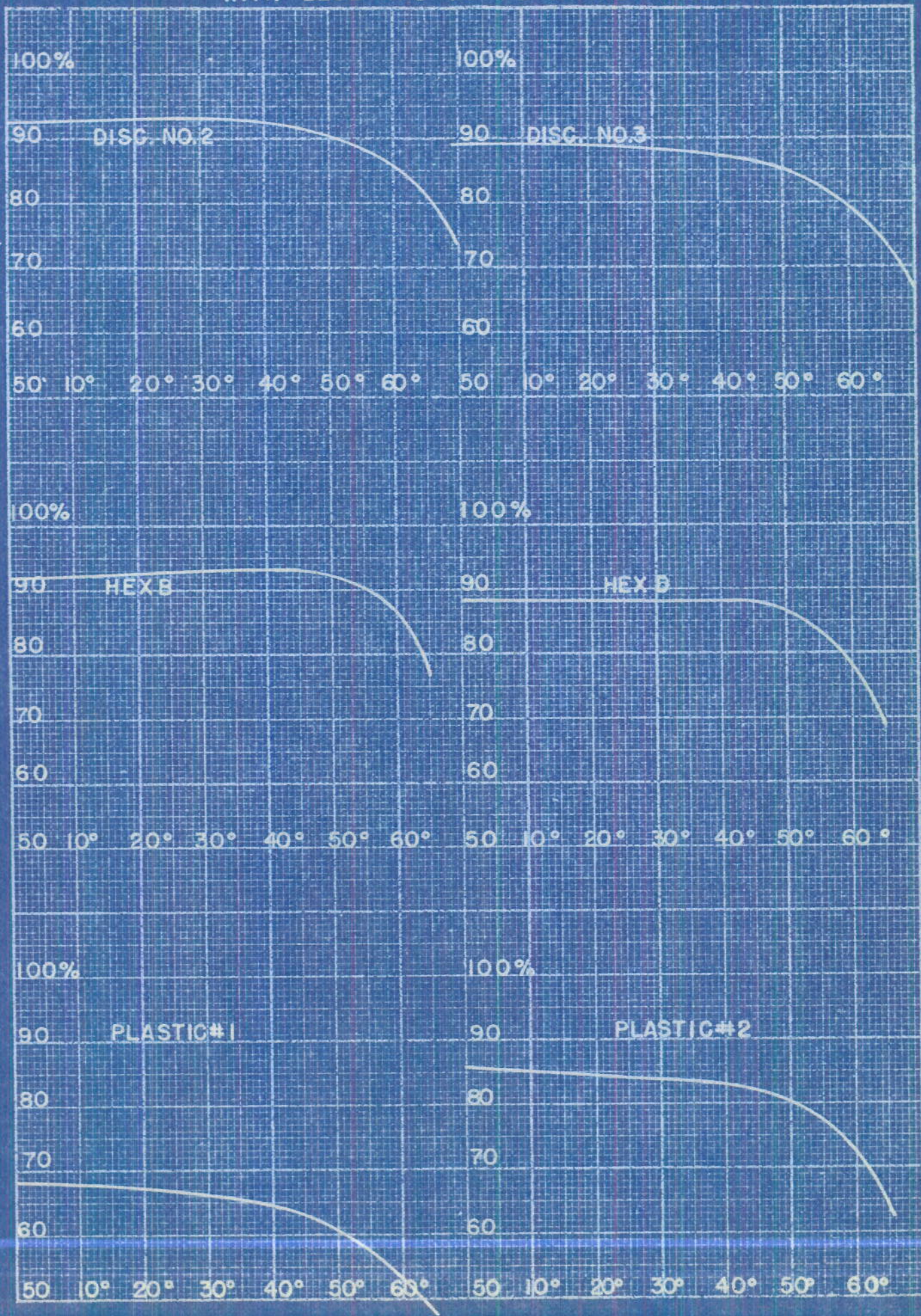




TRANSMISSION CHARACTERISTICS
WITH RED FILTER
PERCENTAGE OF TRANSMISSION
VERSUS
ANGLE OF INCIDENCE


100%
90
80
70
60
50
10°
20°
30°
40°
50°
60°
DISC NO.1
DISC NO.2
HEX A
HEX B
PLASTIC NO.1
PLASTIC NO.2

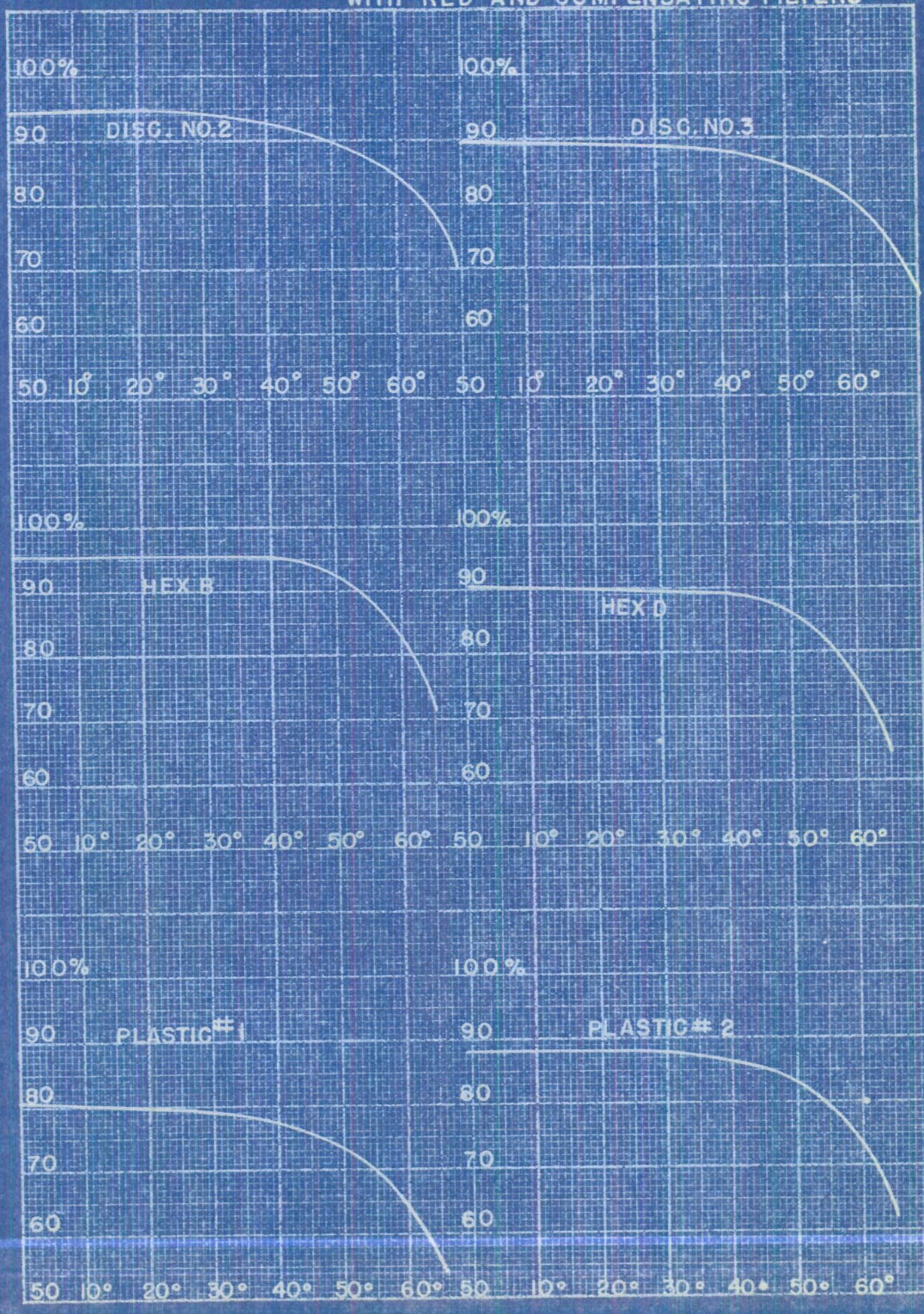
TRANSMISSION CHARACTERISTICS WITH BLUE AND COMPENSATING FILTERS



B-2996

PLATE 9

TRANSMISSION CHARACTERISTICS WITH RED AND COMPENSATING FILTERS



B-2996

PLATE 10

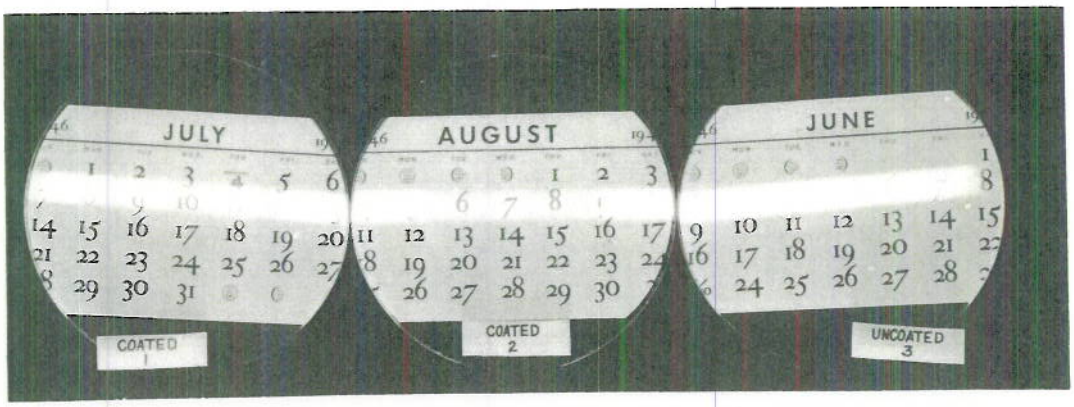


PLATE 11

ANGLE OF INCIDENCE APPROXIMATELY 10°

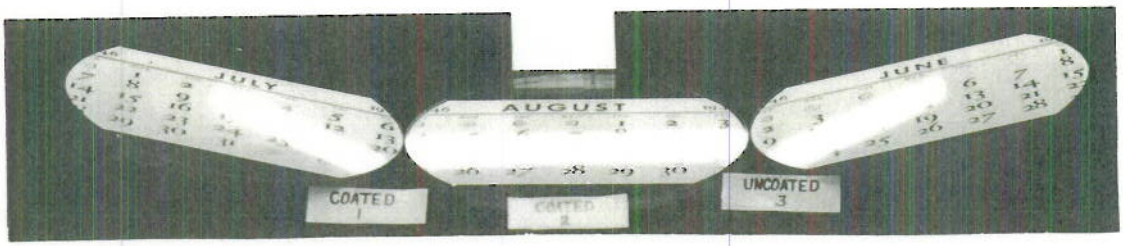


PLATE 12

ANGLE OF INCIDENCE APPROXIMATELY 65°

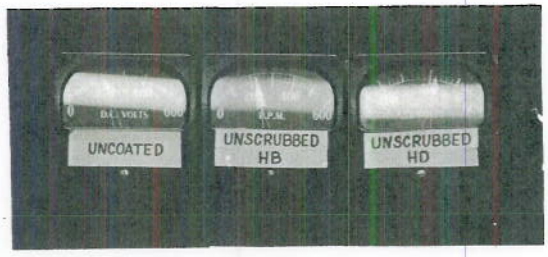


PLATE 13

ANGLE OF INCIDENCE APPROXIMATELY 10°

PLATE 14

ANGLE OF INCIDENCE APPROXIMATELY 65°

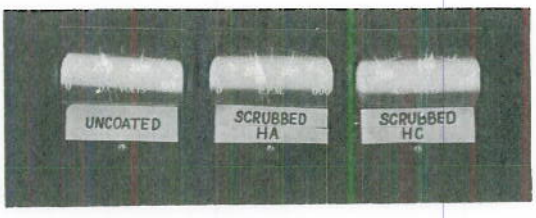


PLATE 15

ANGLE OF INCIDENCE APPROXIMATELY 10°

PLATE 16

ANGLE OF INCIDENCE APPROXIMATELY 65°

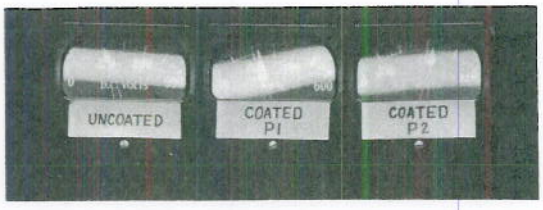
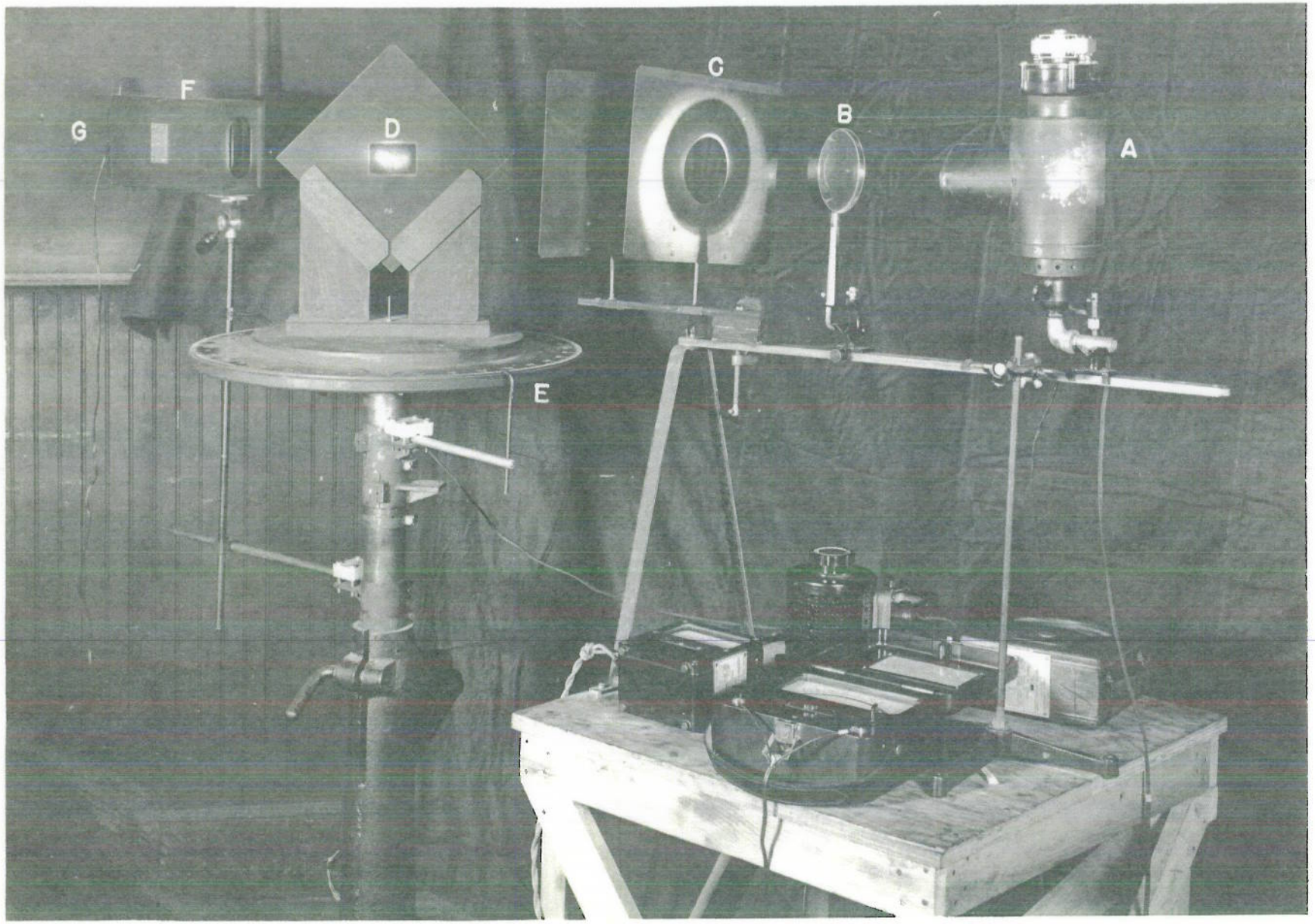


PLATE 17

ANGLE OF INCIDENCE APPROXIMATELY 10°

PLATE 18

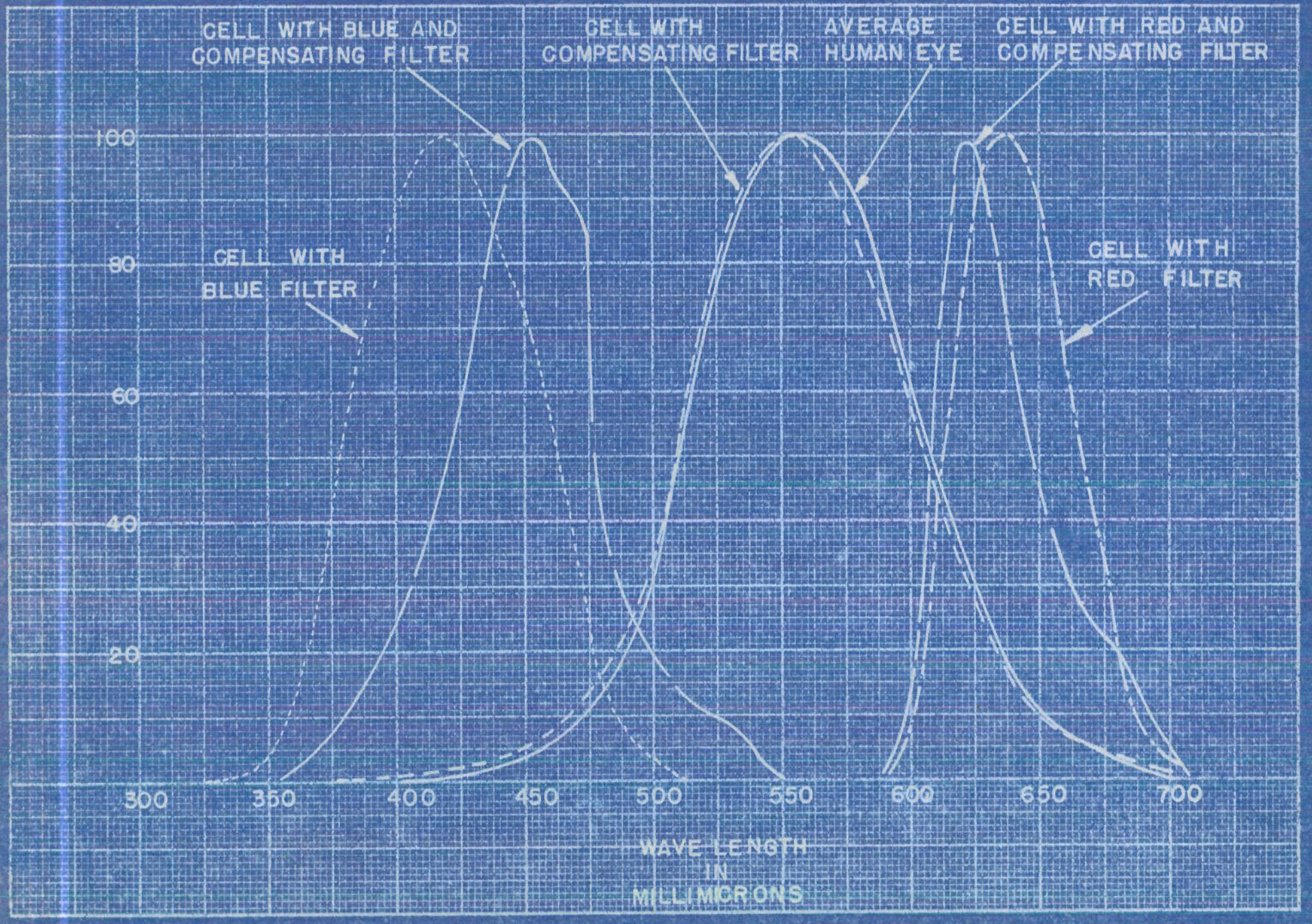
ANGLE OF INCIDENCE APPROXIMATELY 65°



A-LIGHT SOURCE
B-CONDENSING LENS
C-SHIELDS
D-SAMPLE
E-PROTRACTOR TABLE
F-LOUVERED BOX
G-LIGHT CELL

B-2996

PLATE 19



SPECTRAL RESPONSE

PLATE 20

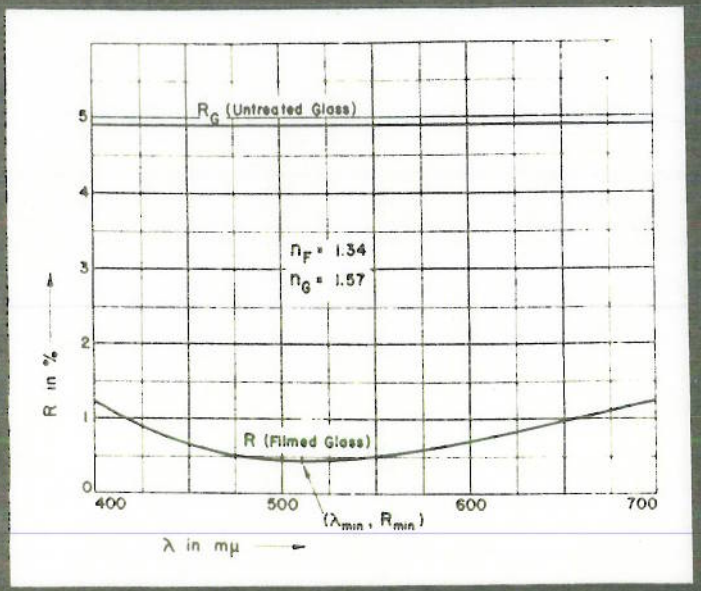


Fig. 3 A typical spectrophotometric reflectance curve for a single glass surface before and after applying a transmission film. If the surface is improperly applied, the worst that can happen is to leave the lens in the condition before coating — there is no loss in transmission

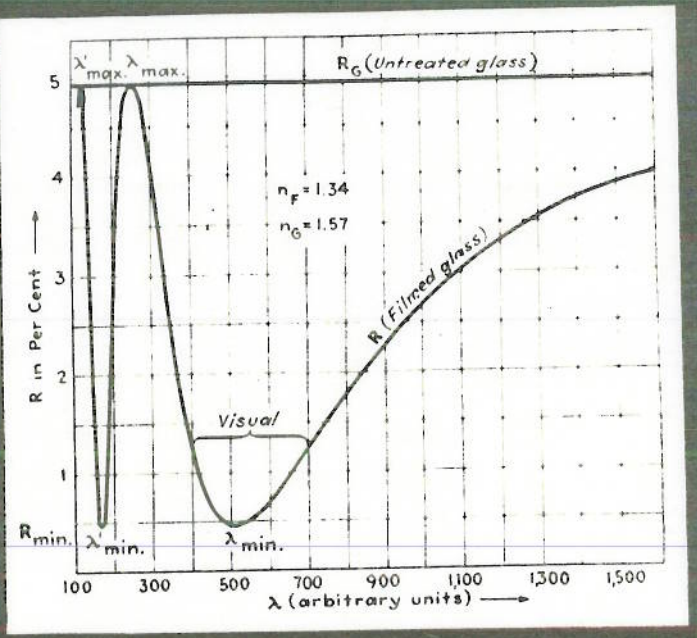


Fig. 4 The curve of Fig. 3 extended to shorter and longer wavelengths. It is to be noted that R_{max} at wavelengths λ_{max} and λ'_{max} where the film thickness is an integral number of half wavelengths is just equal to R_r of the untreated glass

ADDRESS REPLY TO
DIRECTOR, NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.
AND REFER TO:

JJ17/L5-2
1581-52/46
Test No. 593
mew

NAVY DEPARTMENT
OFFICE OF RESEARCH AND INVENTIONS
NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

Subj: Investigation of the Glare Properties of Transparent Material for use on Instrument Windows, Preliminary Report on.

Ref: (a) BuShips ltr. JJ17/Glare P(335a) of 10 May 1945.

1. As a result of the request of reference (a), an experimental procedure to establish the improvement in visibility attending the use of fluoride coated glass windows for instruments has been evolved and the investigation now is underway. Comparative determinations of glare and transmission of the submitted uncoated and coated samples under identical conditions have been considered more pertinent to the problem than determination of actual reflection and transmission factors and data on this basis have been obtained on the 9-1/2" diameter, .375" thick, uncoated glass disc and the two 9-1/2" diamater, .35" thick, coated glass discs.

2. The coated discs have a central area 4" in diameter treated on both sides. The untreated areas were blanked off with velvet finished black paper. A similar area on the uncoated disc was blanked to insure like test conditions. The coated discs were marked No. 1 and 2 and the uncoated disc No. 3.

3. In this investigation an 8" Navy type signalling light was used as a source of collimated light and a Weston foot-candle meter equipped with a Viscor compensating filter was employed. The light cell was shielded from stray light by means of a louvered box.

4. The light source was trained on the foot-candle meter cell and the voltage adjusted so as to produce a scale reading of 100 on the foot-candle meter. Care was taken to maintain a constant lamp voltage and to compensate for fatigue of the foot-candle meter's barrier-layer cell. The discs were carefully cleaned and interposed one at a time between the cell and the light source so that the meter would indicate values of light transmitted through the discs. The discs were then rotated about their vertical axes and readings were obtained for a series of angles of incidence varying from 90 to 30 degrees. These readings were taken as comparative transmission factors for the several angles.

5. In determining the reflection factors or glare properties, the specimen was centered in the light beam and the light cell was arranged so as to intercept the reflected light. The voltage of the light source was

adjusted so as to produce approximately a one-third scale reading on the foot-candle meter for a coated disc. The discs were rotated about their vertical axes and readings taken for a series of angles of incidence varying from 75 to 20 degrees, after the cell had been repositioned in each case to meet the requirement that it be placed in the center of the reflected beam. In estimating the glare reduction attributable to the coating at each angle, the foot-candle meter reading of the uncoated disc was taken as 100%.

6. The results of the preliminary tests are as follows:

Comparative Transmission Percent

	Angles of Incidence								
	90°	80°	70°	60°	50°	45°	40°	35°	30°
Disc No.									
1	95.5	95.5	95.	95.	94	94	93	91	88
2	95.5	.5	95.5	95.	94	93.5	92.5	91	88
3	91	91	91	90.5	90	89	88	86	83

Comparative Reflection Factors

		Angles of Incidence							
		75°	70°	60°	50°	40°	30°	25°	20°
1	F.C.	9.5	9.5	9.5	10.5	14.5	25.5	36.5	52
	%	52	52	52	52	43	30	23	20
2	F.C.	8	8	8.5	10	14.5	26	37	51
	%	60	60	57	54	43	29	22	21
3	F.C.	20	20	20	22	25.5	36.5	47.5	65

Notes: F.C. = Foot-candle meter reading
% = Reduction attributable to coatings.

7. From these results it appears that the coatings increase the visible transmission of the glass discs to collimated light approximately 5% and reduce reflection approximately 50% for angles of incidence above 45°. The coatings are less effective as the angle of incidence approaches 0°.

8. It should be understood that the above results were taken from preliminary data and are subject to revision upon further investigation.

9. At a later date a full report will be submitted giving similar information on the other samples submitted and also data on reflection at wave length above 600 millimicrons and below 500 millimicrons.

Distribution: 5 copies
BuShips, Code 335.

J.D. Haynsworth
Electrical Engineer
Lamp Development and Photometry
I. C. Division