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PHYSICAL OPTICS DIVISION - INSTRUMENTS SECTION

[redacted]

24 October 1943

THE CXR-2 AND CXR-3 NANCY INFRA-RED RECEIVERS

By H. A. Blodgett, J. R. Pruett,
R. Tousey, and I. C. Young

FR-2670

-Report H-2670-

[redacted]

* * *

Approved by:

Dr. R. Tousey - Head, Instruments Section

Dr. E. O. Hulburt
Supt., Physical Optics Division

Rear Adm. A. H. Van Keuren, USN (Ret.)
Director, Naval Research Laboratory

Preliminary Pages ...a-c
Numbered Pages 9
Plates 7
Distribution List.... d

NRL Problem H-72

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ABSTRACT

The CXR-2 NANCY infra-red image receiver was designed to permit air to air and air to surface identification for the pilot of a fighter plane. It differed from other receivers mainly in the eyepiece which consisted of the optics of the Mark-8 aircraft reflector gunsight and permitted great freedom for motion for the pilot's head. The CXR-3 was similar but used a larger objective and was designed for air to air and air to surface identification in multiplace aircraft. Complete laboratory and field data for the receivers are given and possible improvements are discussed.

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ABSTRACT

TABLES

PLATES

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INTRODUCTION

1. The CXR-2 and CXR-3 infra-red image forming receivers were designed and constructed by the Naval Research Laboratory in accordance with a request of March 1944 from the Bureau of Aeronautics to N. R. L. via the Bureau of Ships and authorized on reference (a). A contract for the development of a model of a similar instrument was placed by the Bureau of Ships with The Radio Corporation of America and resulted in the CR described in reference (b). Flight tests of the CXR-2 were carried out at the Naval Air Station, Patuxent River, Maryland in cooperation with N. R. L. and were reported in reference (c). The CXR-2 met a requirement for a small receiver of wide field for use by the pilot of a single seated fighter plane in the identification of other aircraft by means of coded infra-red lights on their wings. The CXR-3 was a high sensitivity instrument for use in a bomber or other plane with more available space than a fighter. Both instruments differed from other infra-red receivers in the occular which was very large and permitted great freedom of motion for the observer.

PURPOSE

2. The purpose for which the CXR receivers were developed was to provide a recognition system for air to air or air to surface craft. All friendly air and surface craft would carry infra-red lights. These lights would be coded and for aircraft would be of as low candlepower as practicable to minimize power consumption and wind resistance and to increase security.

3. For air to air recognition, the receiver would be mounted directly in front of the pilot. Since there is very little available space in an F6F or F7F type fighter aircraft, it was required that the receiver be as small as possible. It was desired, however, that it be as sensitive as possible and have a thirty degree field of view. Furthermore in order that the pilot would be free to move about, it was required that the presentation be similar to that of a radar screen and not necessitate the use of a small eyepiece. Obviously any instrument design had to be a compromise between the various requirements.

4. For air to surface recognition, the requirements for size and field were less strict since in this case it was intended that the instrument be used in multiplace aircraft where more space is available and be supported on a moveable mount.

DESIGN OF THE RECEIVERS

5. The CXR-2 and CXR-3 receivers like the U.S. Navy C-3 receiver used the 1P25 electron image tube. They differed from the C-3 principally in the optical components which were designed to meet certain special requirements.

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6. The first special requirement for the airborne receiver was that the presentation be somewhat similar to a radar or television screen. The reason for this was that pilots have found it impossible when in action to use instruments with small eyepieces which have to be held close to the eye. It was necessary that the viewing device permit great freedom of motion for the pilot. This requirement was met by using the optics of the Mark-8 aircraft reflector gunsight as occular for the receiver. Since the Mark-8 reflector sight has been found to be satisfactory in this respect as a gunsight, it was felt that its use as an eyepiece for the receiver would also be satisfactory. The diameter of the occular was $3\frac{1}{4}$ inches, and the pilot could observe with both eyes with considerable freedom for head movement.

7. The second requirement was that the receiver for use by a fighter pilot be as short and small as possible and still have a thirty degree field of view and good sensitivity. For a thirty degree field, a short focus objective was required, and the best available lens for the purpose was the "Zeiss Sonnar" f/1.5 having a 50mm. focal length. The CXR-2 was built with this lens. For a second receiver to be used in multiplace aircraft, the size and field requirements were somewhat relaxed, and the CXR-3 was constructed using the C-1 Schmidt as an objective.

CONSTRUCTION DETAILS

8. Plate 1 shows the CXR-2 and plate 2 the CXR-3. The dimensions and characteristics of these instruments are given in table 1. Drawings showing the design and construction details of the two receivers are contained in plates 5, 6, and 7. The Mk-8 sight (or the Mk-30 torpedo director sight) was adapted by removal of the reflector plate and filter assembly, lamp housing, reticle assembly, and also the optical flat above the reticle. In the present design the eyepiece was carried on threads and could be focused, but performance has shown that this adjustment was not necessary. In both receivers the objective also could be focused, although it was necessary to remove the housing over the Schmidt in the CXR-3 to make this adjustment. In the final instruments a fixed focal length objective would be satisfactory.

9. In the designs of the receivers, no particular effort was made to seal them off in an atmosphere of dry nitrogen as would be necessary in a production model; only minor changes would be required, however, to accomplish this. In the design of the CXR-3, a seal around the eyepiece would make it airtight.

10. In the CXR-2 a field corrector lens was used to make sharp the definition over the whole field. This was a double concave lens having a radius of curvature of 59mm. on one side and 26mm. on the other. The side having the 59mm. radius of curvature was mounted in

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contact with the face plate of the 1P25 image tube. The lens curved the field of the Sonnar to a sharp focus over the curved face of the tube. It also produced pincushion distortion which was not objectionable and reduced the field from 31 degrees to 29 degrees.

11. A Zeiss R-10 red filter was used over the objective of the CXR-2 to protect the lens, and also to reduce the effect of a moonlit background.

12. The power supply furnished with the receivers was like the one for the U.S. Navy C-1 or C-3 receivers with a few minor changes. It was run from a dry battery of 7.5 volts. Another power supply was available which ran from 24 volts direct current. The power supply circuit diagram is shown in plate 3.

PERFORMANCE

Occular:

13. The occular used with the CXR-2 and 3 receivers permitted the observer to use both eyes with considerable freedom of motion. Viewing conditions were fully as flexible as with the Mk-8 aircraft gunsight. However, the instrument offered somewhat less ease of viewing than a radar screen or dial on the instrument panel.

14. The question of the optimum occular focus received considerable study. Adjustments between 0 and -4 diopters were used with the virtual image between infinity and 25cm. respectively from the eyes. As the adjustment was changed, three principal effects were observed.

15. First, the lateral freedom for motion of the observer's head was increased as the focus became more negative. At infinity it was possible to view only the central portion of the field with both eyes at once, and the head could not be moved more than $\frac{1}{2}$ inch without loss of field for binocular vision. When the eyepiece was adjusted with the virtual image at 25cm., considerable lateral freedom for motion of the head was possible. The whole field was easier to view and could be easily seen with both eyes, and the image appeared smaller.

16. The second effect which was observed, was the decrease in sensitivity for all settings except that at zero diopters as the distance from the occular to the observer's head was increased. This decrease in sensitivity became more rapid as the eyepiece adjustment was made more negative. Table 2 shows this effect on sensitivity for an eyepiece setting of -4 diopters. When the eyepiece was set at infinity, the distance from the observer to the occular was not critical, and the sensitivity remained unchanged as the observer moved back. At all other settings of the occular, maximum sensitivity was attained with the eyes as close as possible to the eyepiece.

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17. When the eyes were as close as possible to the eyepiece, the threshold still varied with the eyepiece setting. The variation of threshold due to this third effect is shown in plate 4 as a function of diopters occular setting. It can be seen that the minimum threshold, or maximum sensitivity, for a point source occurred at an adjustment of approximately -1 diopter for observers with normal vision. This was due to the fact that, when looking into the receiver, the eyes tended to focus for infinity; however, due to spherical aberration of the lens when the pupils were dilated, they were myopic to the extent of -1 diopter.

18. It was finally concluded that -1 diopter was the optimum adjustment for the occular, since it yielded the greatest sensitivity and gave more freedom of motion for the observer than the zero setting, and yet the decrease in sensitivity with distance from the eyepiece was not rapid.

19. With this decided, the sensitivity of the Mk-8 occular compared with that of the C-3 eyepiece was investigated next. In theory, the sensitivity would be inversely proportional to the square of the focal lengths; therefore it was expected that the sensitivity with the C-3 would be 6 times that with the Mk-8. In experimental comparisons of the two eyepieces, it was found that the C-3 was only 3 times more sensitive than the Mk-8, as can be seen from plate 3. The reason for this disagreement appeared to be that the image seen in the eyepiece was not a true point of light but a small disk. In the higher powered eyepiece, the image appeared larger than in the Mk-8 eyepiece, so the loss in flux acceptance by the eye when using the lower power eyepiece was partially compensated for by the increase in image brightness due to the reduction in its apparent size.

POINT SOURCE SENSITIVITY

20. In addition to the occular effects already discussed, the sensitivity of an infra-red receiver for viewing a point source against a dark background is directly proportional to the area of the objective. The ratio between the areas of the C-3 Schmidt and the Zeiss Sonnar is 2.9, so it would be expected that the CXR-3 would be 2.9 times as sensitive as the CXR-2. In experiment this was found to be approximately true. By referring to table 1, it is seen that the two thresholds gave a ratio of about 2.5 instead of the 2.9 predicted by theory. This difference can easily be attributed to the differences in the sensitivities of the 1P25 image tubes used in the two instruments.

21. In comparison with the C-3, actual experiment has shown that the C-3 was approximately three times as sensitive as the CXR-3 and nine times as sensitive as the CXR-2. This was in agreement with what was expected from the objectives apertures and the relationship found between the eyepieces.

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RESOLUTION

22. The resolution of an infra-red receiver of the image tube type may be limited by the image tube, the objective lens, or the eye. At low levels of image brightness the eye will limit the resolution, but not at high levels. The resolution of the Sonnar objective lens with the field corrector was 56 lines/mm. at the center of the field while the Schmidts of the CXR-3 and the C-3 resolved 30 lines/mm. The very best 1P25 tubes resolved 24 lines/mm., but the average was nearer 15 lines/mm. Thus it is seen that the tube was the component which limited the resolution in these instruments at other than very low brightness, and in the latter case it was the eye. It was found possible to resolve point sources separated by $1\frac{1}{2}$ to 2 minutes of arc when they were fairly bright and when a very good tube was used.

FIELD OF VIEW AND MAGNIFICATION

23. The field of view of the receivers depended on the objective system and the electronic magnification. For an electronic magnification of 0.65 the field of view of the CXR-2 was 29 degrees and that of the CXR-3 was 27 degrees; the overall magnifications of the CXR-2 and CXR-3 receivers were 0.74 and 0.87 respectively. Image tubes were frequently found; however, which focused sharply only for greater electronic magnification. In this case, the field was considerably reduced, sometimes by as much as one third, and the overall magnification was proportionately increased.

FIELD TESTS

24. The CXR receivers were tested in the field, both on the ground and in the air. For the ground tests, the instruments were mounted ashore, and a calibrated source was placed aboard ship. The ship ran away from the receivers until the source was at threshold as seen by several experienced observers. At the same time atmospheric transmission measurements were made with a Maxwellian view telephotometer. The tests were made on both dark and bright nights. The range data were found in good agreement with values computed from the receiver thresholds measured in the laboratory and the atmospheric attenuation values for the particular night.

25. Flight tests of the CXR-2 were reported in reference (c). Air to air ranges of 1.75 miles were obtained at altitudes between 4000 and 6000 feet with ground visual ranges between 6 and 10 miles. The source on the target plane was an infra-red beacon of 570 C. P., and it was coded.

26. From the flight tests, the field factor can be estimated which must be applied to laboratory measurements of the receiver sensitivities in order to obtain sensitivities for use under operating conditions. From the data of reference (c) and assuming an attenuation of 0.7 per mile, which is little more than a guess at the value for 5000 feet, the illumination at 1.75 miles from the beacon was

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$I = 570 \times 0.7^{1.75} / 1.75^2 = 100$ S.M.C. The receiver threshold as measured in the laboratory was approximately 1 S.M.C. Thus we may take 100, very approximately, as the field factor to be applied to the laboratory threshold to obtain the field threshold for air to air recognition.

26. It should be noted that in the air to air tests, the pilot had had comparatively little experience in the use of the equipment and also was troubled with extraneous light from the cockpit lighting and possibly from the infra-red from the plane's engine. With some attention to these points and with more training it should be possible to thus reduce the field factor to some extent. Whether it may be possible to reduce the field factor from 100 to, say, 10 and thereby increase the effective operating range of the equipment by a factor of 2 or 3 has not been determined.

IMPROVEMENTS

27. There have been improvements in the image tube used in the CXR receivers since they were developed and tested. A new tube, RCA MA-4, has been built which operates at 16 K.V. and which has a phosphor of much shorter persistence than the screen in the 1P25. Use of the new tube in the CXR receivers would lengthen them approximately one inch. The sensitivity of the new tube is 5 to 8 times greater than for the 1P25, and so recognition ranges from 2 to 3 times greater can be expected. For the source used in the tests reported in reference (c), ranges of five miles or more would be obtained. Furthermore, it is probable that the new short persistence phosphor will decrease the field factor since it will permit easier recognition of a coded signal.

28. The CXR-2 receiver could also be improved by the use of a larger objective lens. A captured lens for a German development similar to the CXR-2 is available and has a 50mm. focal length and an aperture of f/1.0. Use of this lens would increase the sensitivity of the receiver by a factor of 2 and the range by 30 to 40 percent.

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REFERENCES

(a) Bureau of Ships Project #386/45

(b) NRL ltr S-S70-4(1)(423) 4869 of 18 Apr 1945 to BuShips; "CR NAN Receiver: Optical Characteristics and Comparison With C-3, CXR-2, and C-4 Receivers."

(c) NAS. Patuxent River Report of 5 Feb 1945 on Project TED PTR 31697.0 "CXR Equipment in F6F-3N Aircraft - Prototype and Test of."

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TABLE 1

CHARACTERISTICS OF THE CXR-2, CXR-3, and C-3 RECEIVERS:

	CXR-2	CXR-3	C-3
Length	26.0cm	35.0cm	30.0cm
Maximum diameter	10.7cm	14.4cm	13.2cm
Objective;			
Focal length	50mm	59mm	59mm
Diameter	33mm	84mm	84mm
Relative light gathering power	0.35	1.00	1.00
Central resolution lines/mm	56	30	30
Field corrector	double concave	none	none
Eyepiece;			
Diameter	82mm	82mm	12mm
Equivalent focal length	4.4cm	4.4cm	1.8cm
Image tube	1P25	1P25	1P25
Receiver;			
Magnification	0.74	0.87	2.1
Field of view	$19^{\circ}$to 29°	$18^{\circ}$to 27°	$18^{\circ}$to 27°
Threshold sensitivity (sea mile candles)			
Very best	0.85	0.35	0.10
Average	2.5	1.0	0.30

TABLE 2

CHANGE IN THRESHOLD WITH DISTANCE FROM EYES TO OCCULAR
(virtual image 25 cm. behind occular)

Distance (inches)	Threshold - (s.m.c.)
3	0.85
6	1.08
9	2.12
12	3.07
15	3.35
18	4.2
21	6.1
24	6.5
30	11.2
36	17.0

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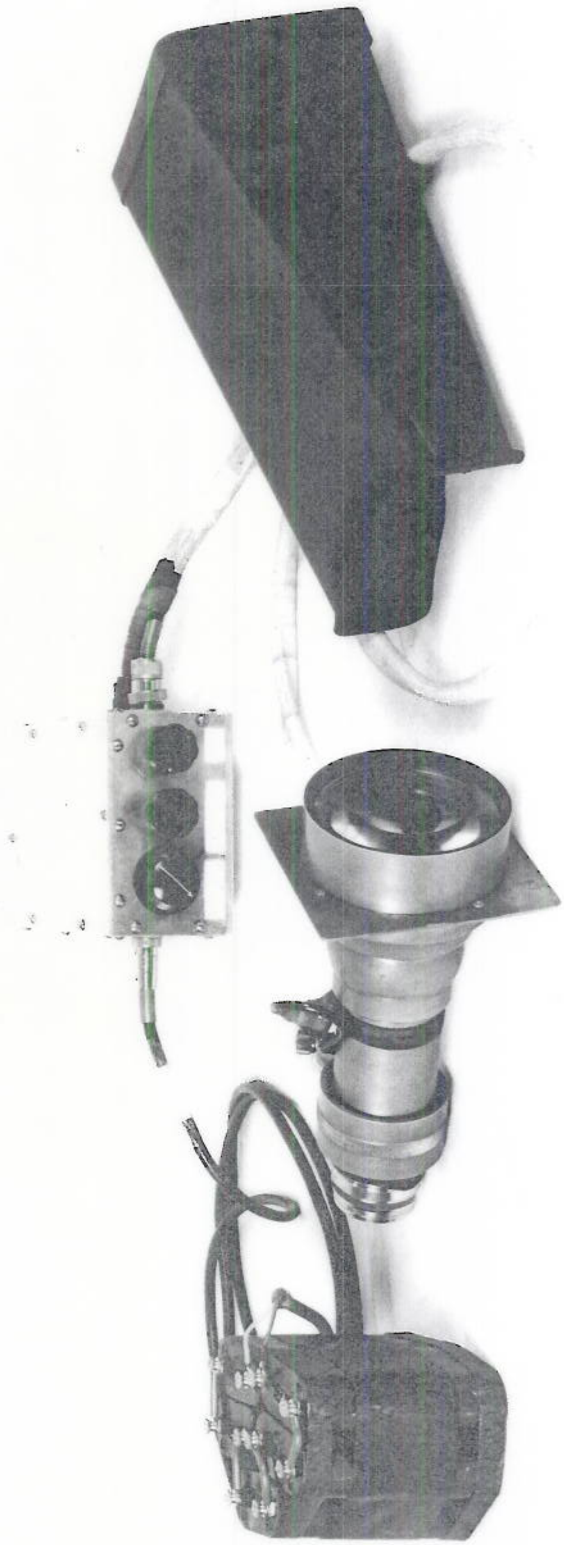

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PLATE I

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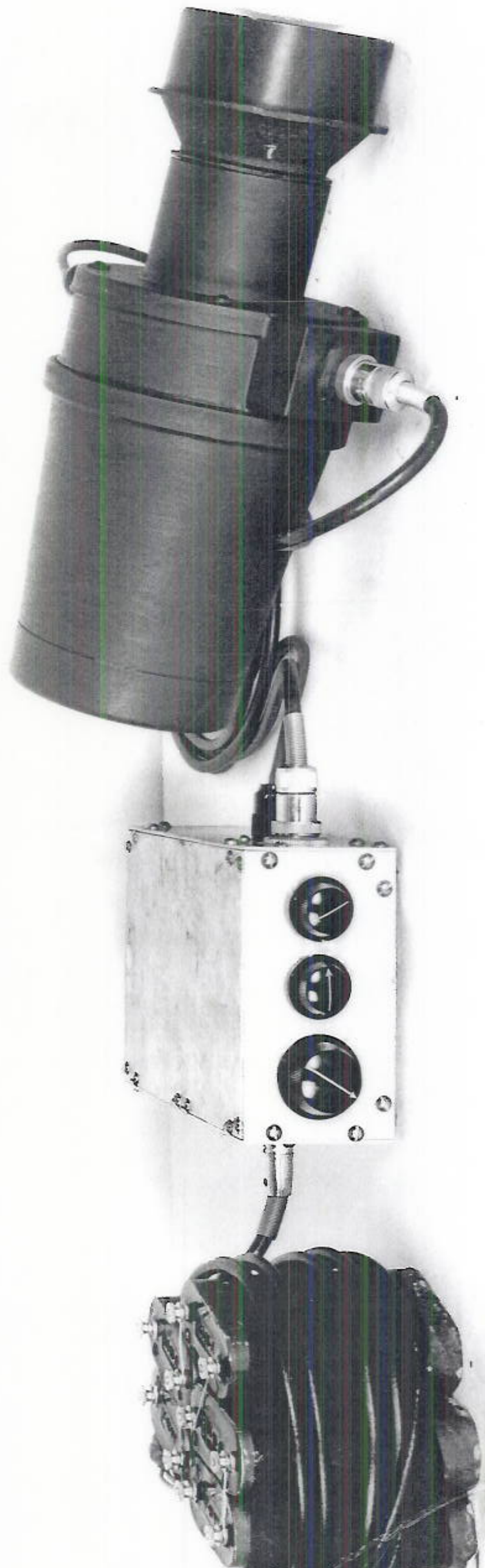

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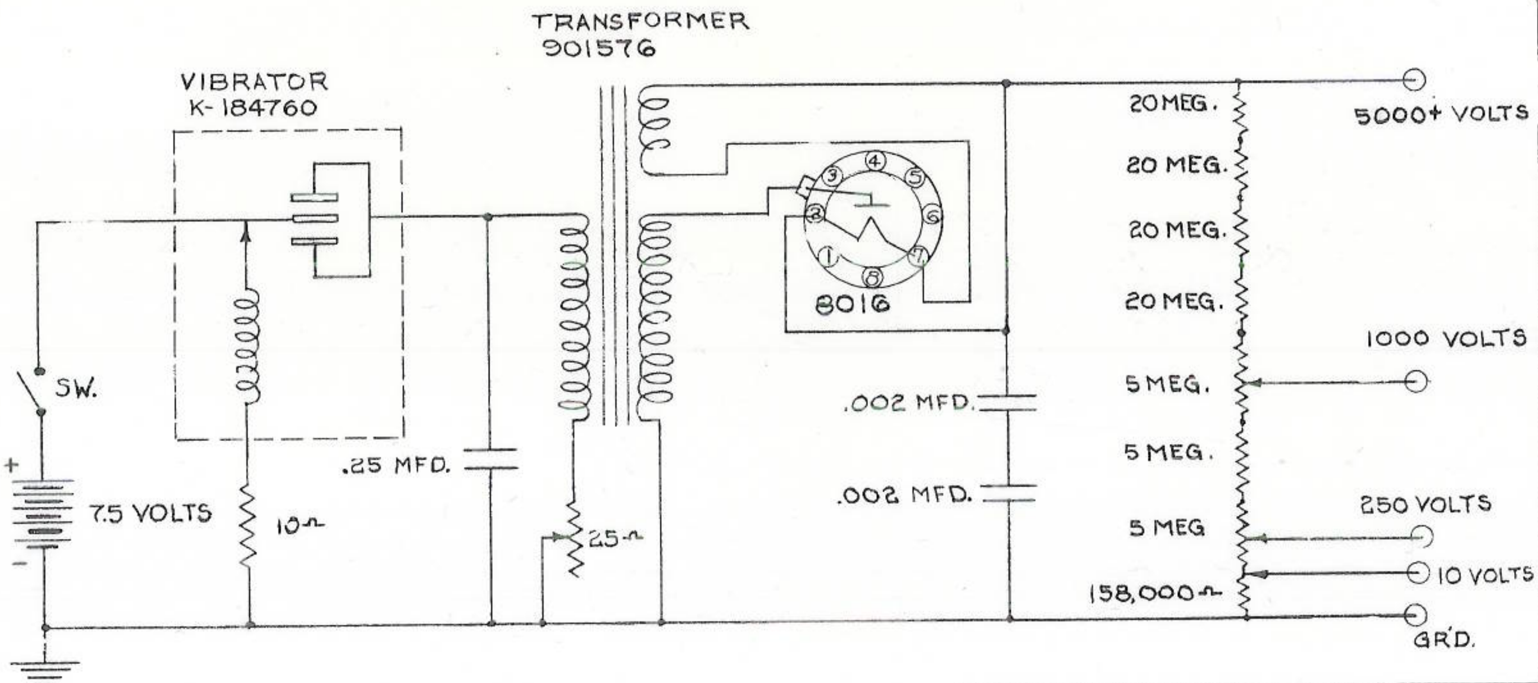
PLATE 2



NAVAL RESEARCH LABORATORY
WASHINGTON, 20, D.C.

POWER SUPPLY
WIRING DIAGRAM

USED ON- TYPE CXR RECEIVERS
DRAWN BY- H. Blodgett DATE- 9-26-44
CHECKED- J. R. Pruett
APPROVED- L. C. Young Lieut Comdr. U.S.N.R.

PLATE 8

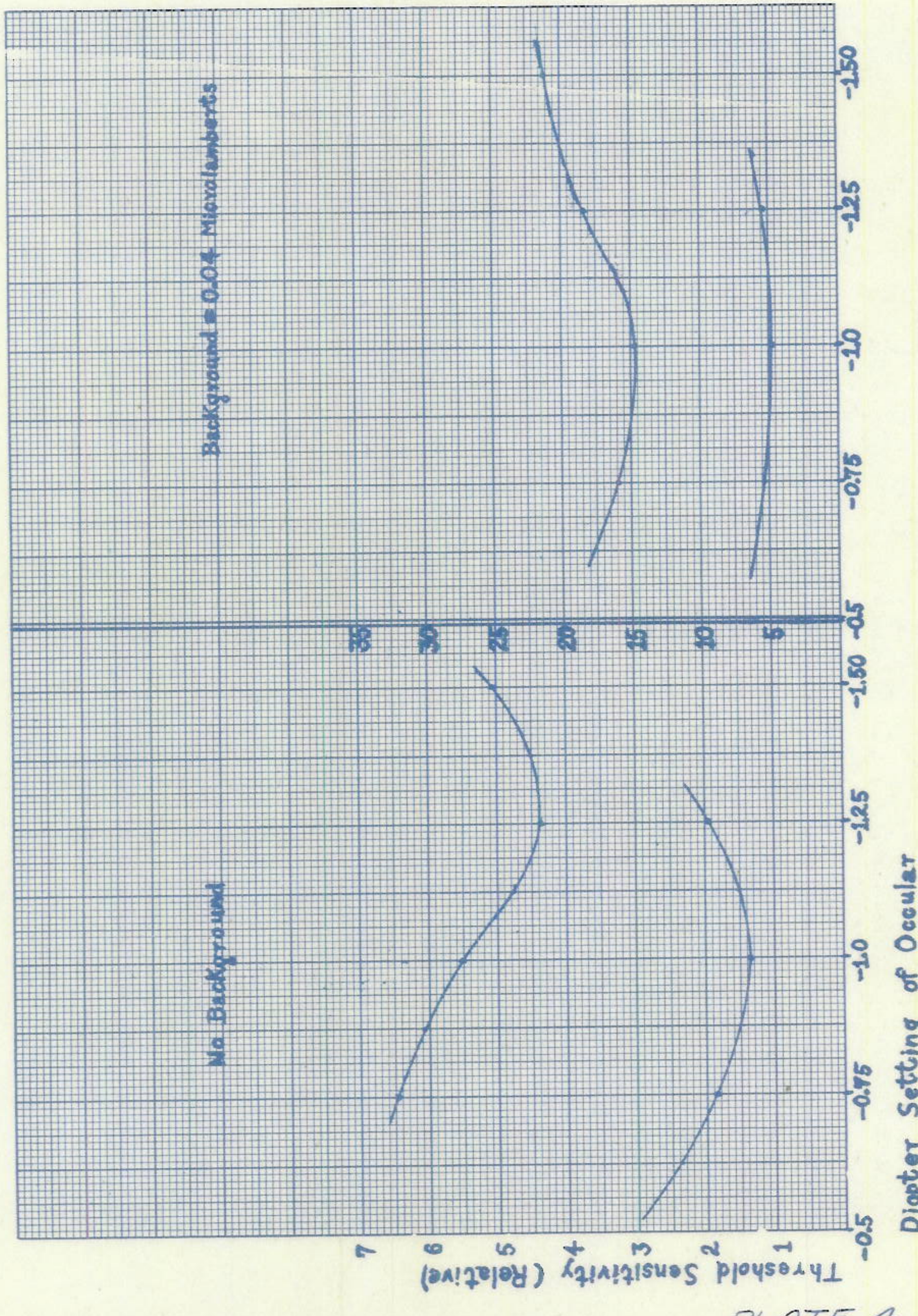
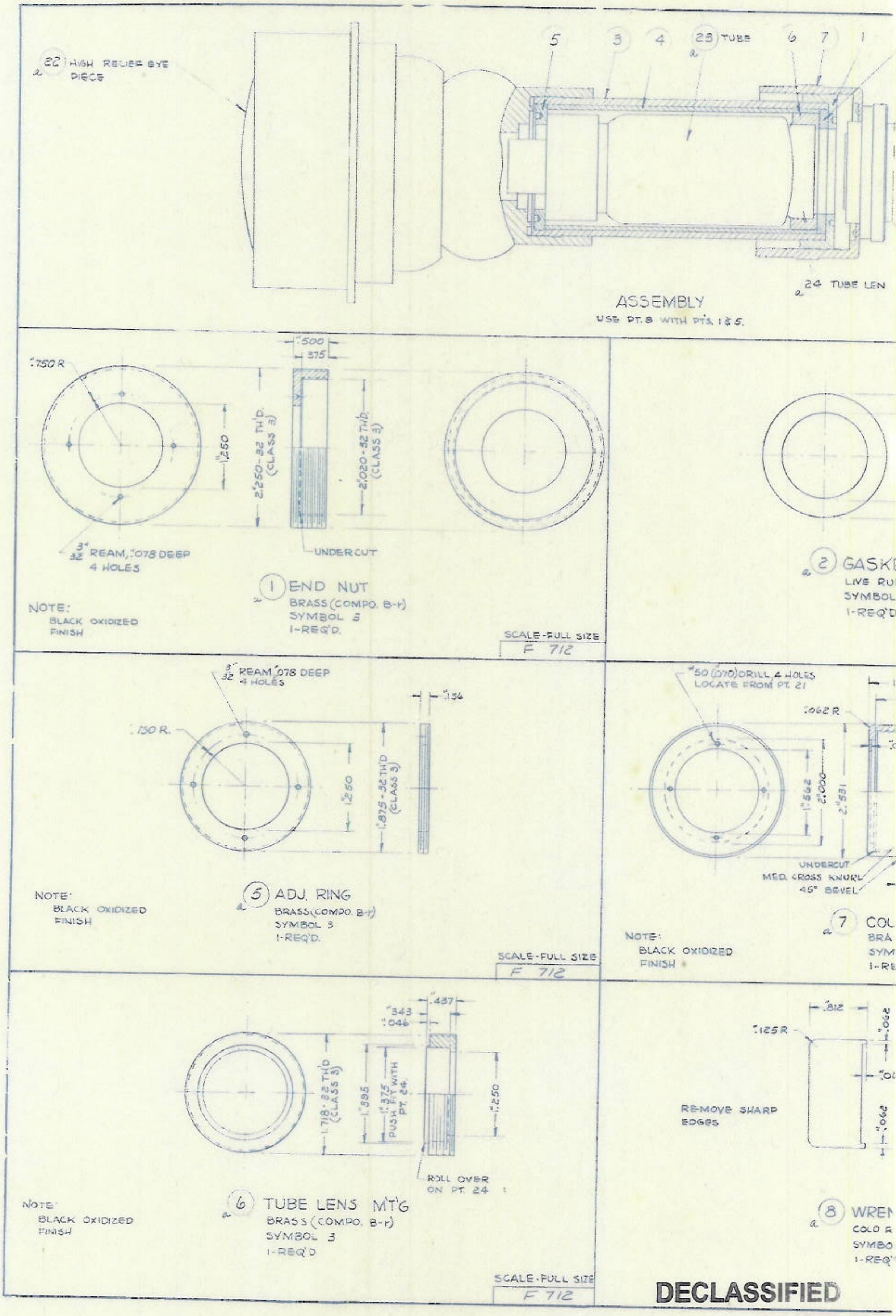
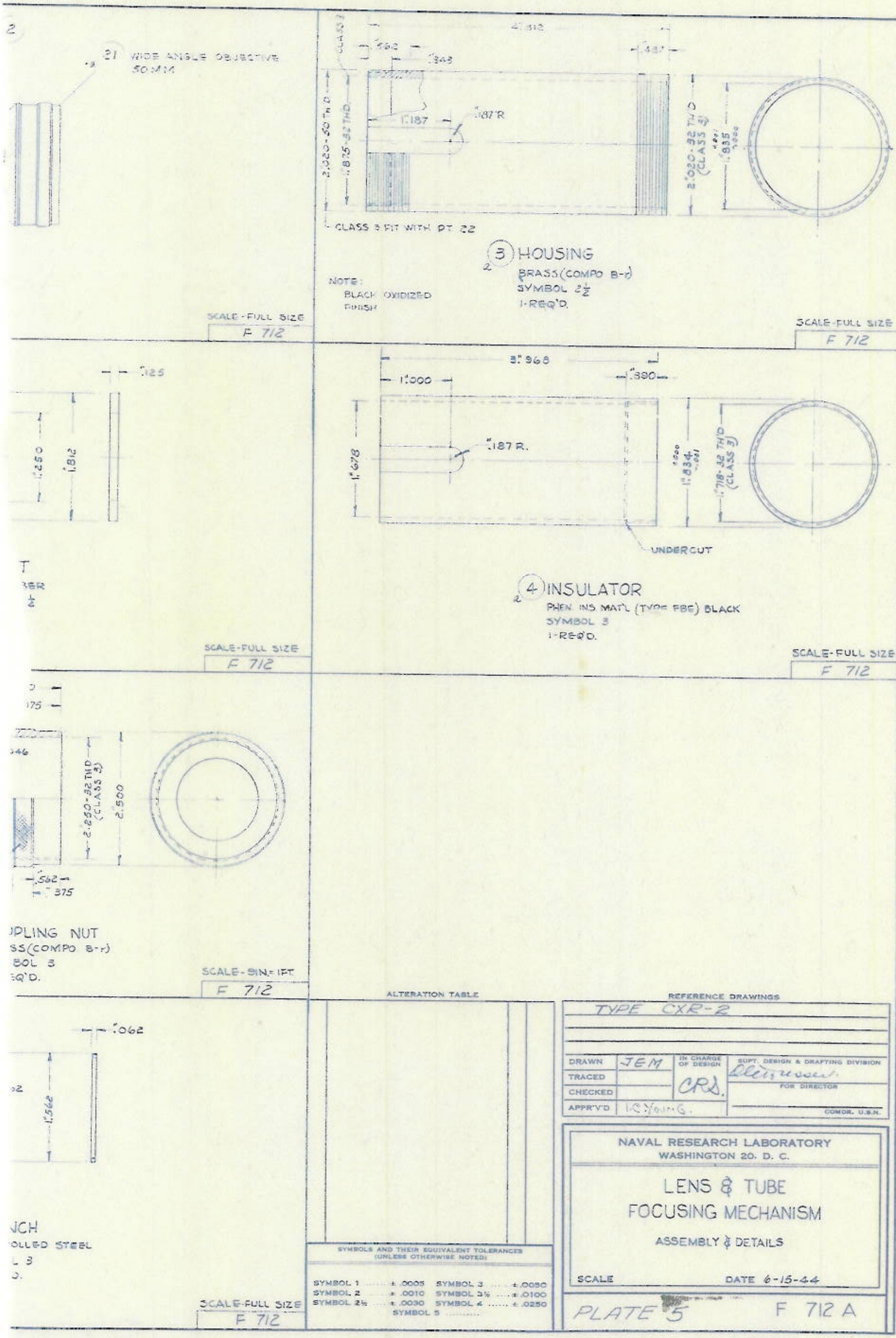

No Background
Background = 0.04 Microlamberts
Threshold Sensitivity (Relative)
7 6 5 4 3 2 1
35 30 25 20 15 10 5
Diopter Setting of Occular
-0.5 -0.75 -1.0 -1.25 -1.50
-0.5 -0.75 -1.0 -1.25 -1.50

PLATE 4


22 HIGH RELIEF EYE PIECE
5
3
4
23 TUBE
6
7
1
24 TUBE LEN
ASSEMBLY
USE PT. 8 WITH PTS. 1 & 5.
.750 R
.500
.375
1.250
2.250-32 TH'D. (CLASS 3)
2.020-32 TH'D (CLASS 3)
3/32" REAM, .078 DEEP 4 HOLES
UNDERCUT
1 END NUT
BRASS (COMPO. B-r)
SYMBOL 3
1-REQ'D.
NOTE: BLACK OXIDIZED FINISH
SCALE-FULL SIZE
F 712
2 GASKE
LIVE RUBE
SYMBOL 3
1-REQ'D.
3/32" REAM .078 DEEP 4 HOLES
.156
.750 R.
1.250
1.875-32 TH'D (CLASS 3)
5 ADJ. RING
BRASS (COMPO. B-r)
SYMBOL 3
1-REQ'D.
NOTE: BLACK OXIDIZED FINISH
SCALE-FULL SIZE
F 712
#50 (.070) DRILL, 4 HOLES LOCATE FROM PT. 21
.062 R
1.562
2.000
2.531
UNDERCUT
MED. CROSS KNURL
45° BEVEL
7 COU
BRA
SYM
1-RE
NOTE: BLACK OXIDIZED FINISH
.437
.343
.046
1.718-32 TH'D (CLASS 3)
1.395
1.375 PUSH FIT WITH PT. 24.
1.250
ROLL OVER ON PT. 24
6 TUBE LENS MT'G
BRASS (COMPO. B-r)
SYMBOL 3
1-REQ'D
NOTE: BLACK OXIDIZED FINISH
SCALE-FULL SIZE
F 712
.812
.125 R
.062
REMOVE SHARP EDGES
8 WREN
COLD R
SYMBO
1-REQ'


21 WIDE ANGLE OBJECTIVE 50 MM
CLASS 3 FIT WITH PT. 22
3 HOUSING
BRASS (COMPO B-r)
SYMBOL 2½
1-REQ'D.
NOTE: BLACK OXIDIZED FINISH
SCALE-FULL SIZE
F 712
UNDERCUT
4 INSULATOR
PHEN. INS MAT'L (TYPE FBE) BLACK
SYMBOL 3
1-REQ'D.
SCALE-FULL SIZE
F 712
PLING NUT
SS(COMPO B-r)
BOL 3
EQ'D.
SCALE-9IN.=1FT
F 712
NCH
OLLED STEEL
L 3
SCALE-FULL SIZE
F 712
ALTERATION TABLE
REFERENCE DRAWINGS
TYPE CXR-2
DRAWN JEM
TRACED
CHECKED
APPR'V'D
IN CHARGE OF DESIGN CRS.
SUPT. DESIGN & DRAFTING DIVISION
FOR DIRECTOR
COMDR. U.S.N.
NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.
LENS & TUBE
FOCUSING MECHANISM
ASSEMBLY & DETAILS
SCALE
DATE 6-15-44
SYMBOLS AND THEIR EQUIVALENT TOLERANCES (UNLESS OTHERWISE NOTED)
SYMBOL 1 ± .0005 SYMBOL 3 ± .0050
SYMBOL 2 ± .0010 SYMBOL 3½ ± .0100
SYMBOL 2½ ± .0030 SYMBOL 4 ± .0250
SYMBOL 5
PLATE 5
F 712 A

SHEET

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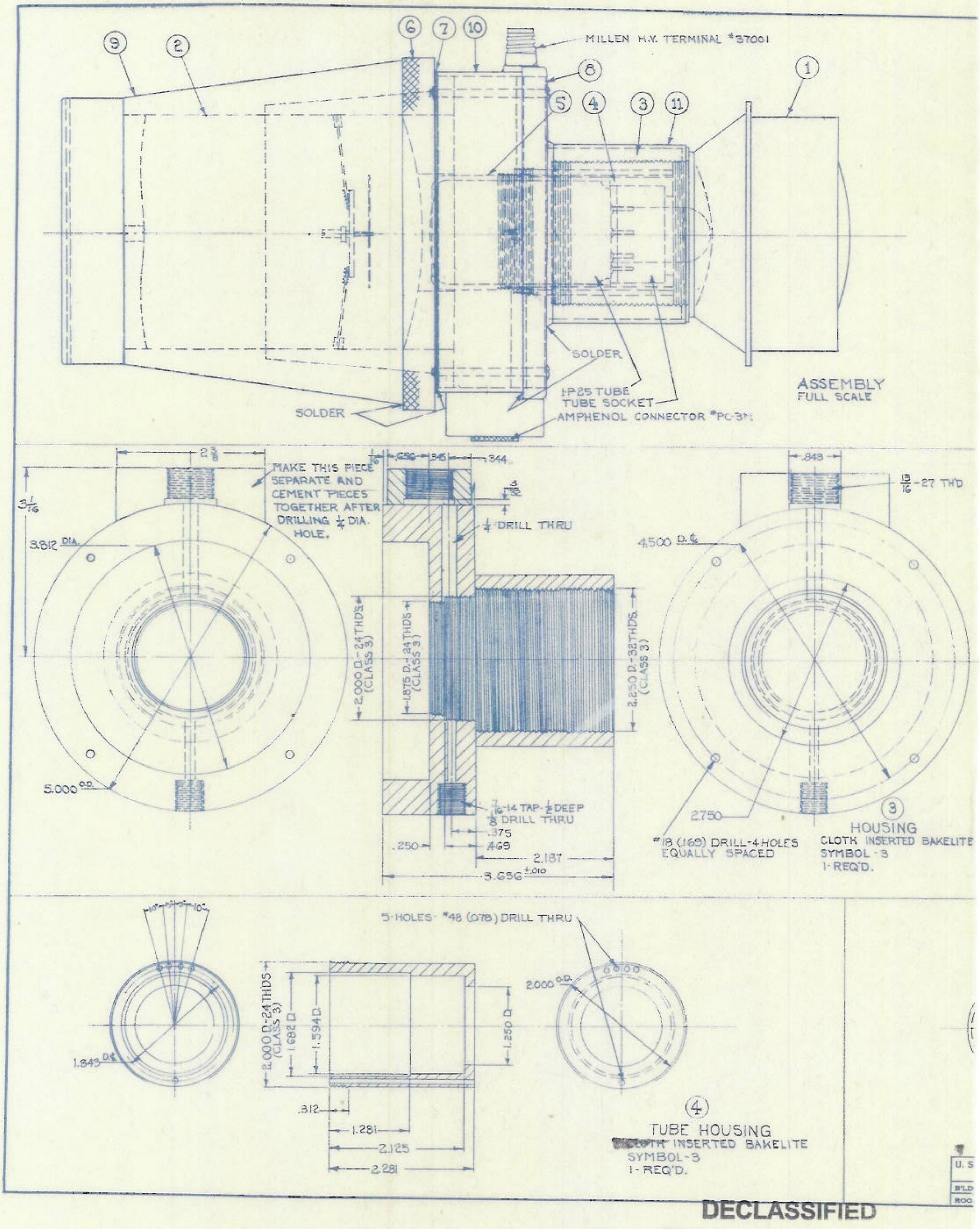

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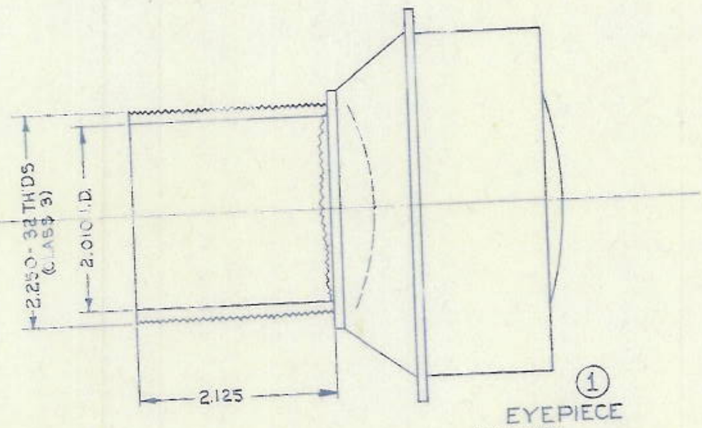

① EYEPIECE
ALUMINUM
SYMBOL-3
1-REQ'D.

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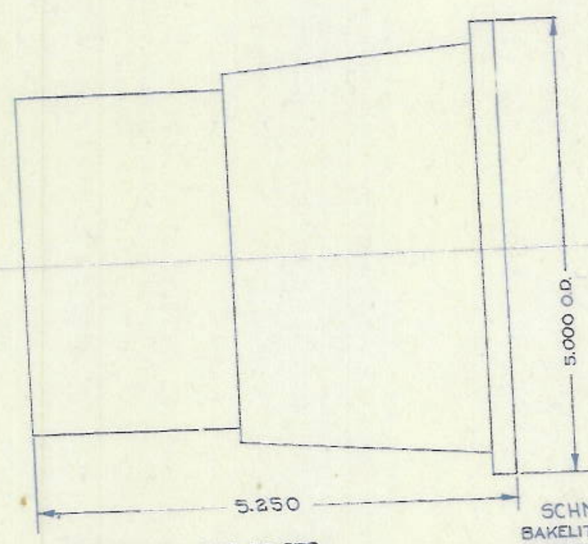
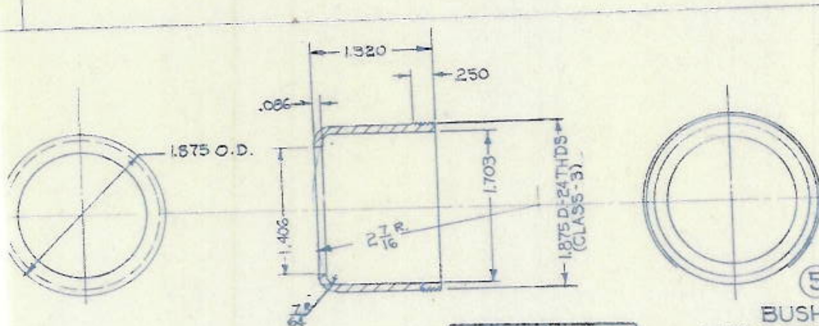


② SCHMIDT OPTICS
BAKELITE
SYMBOL-3
1-REQ'D.

SUPPLIED BY BUR. OF ORD.

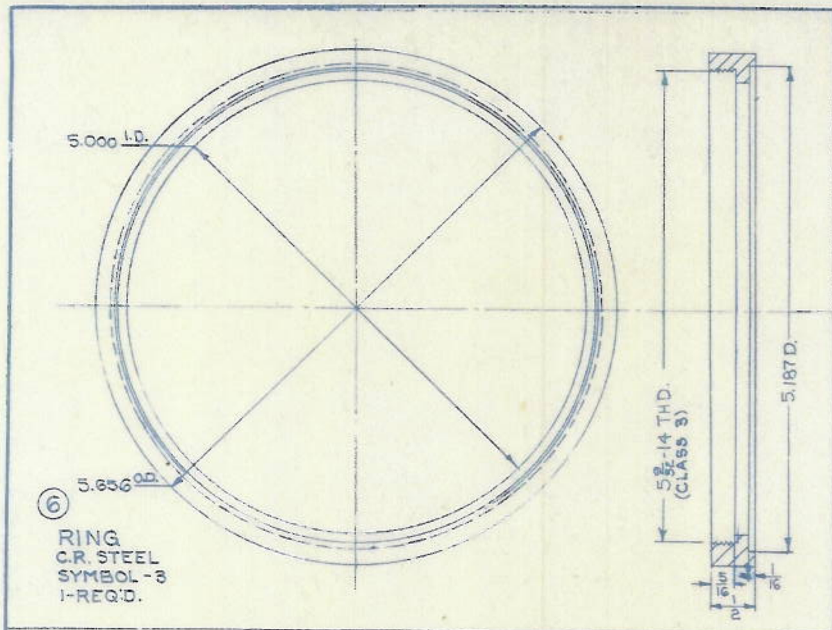


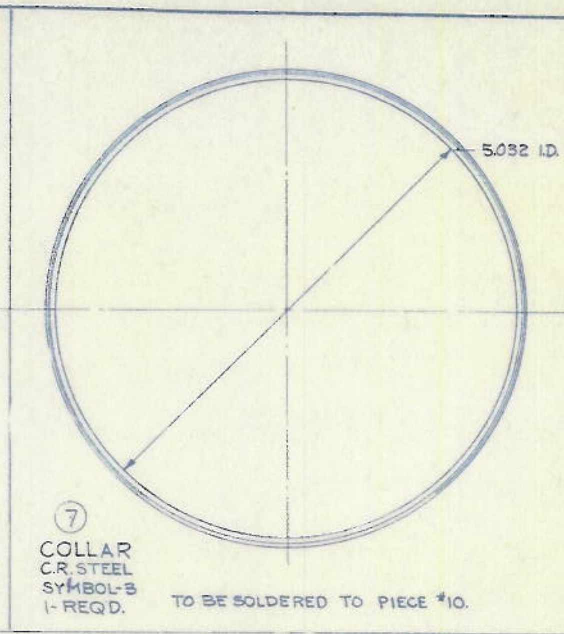
⑤ BUSHING
CLOTH INSERTED BAKELITE
SYMBOL-3
1-REQ'D.

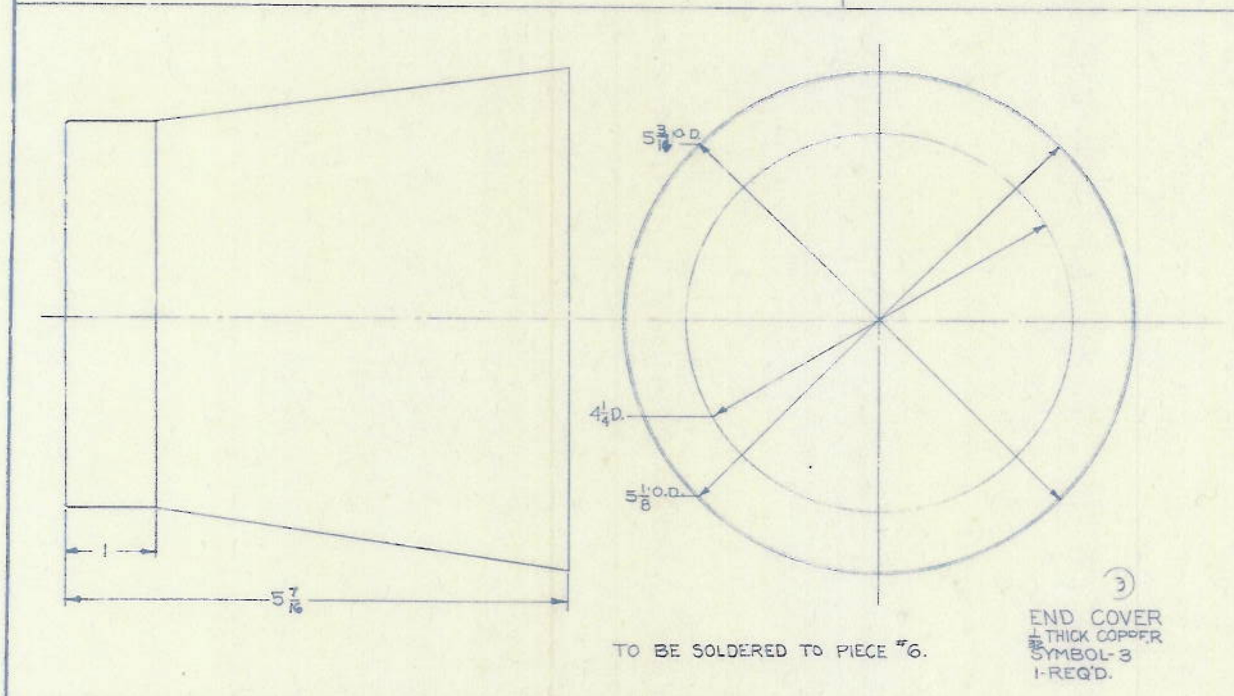
CHECKED	G.T.M.
DATE	10/28/44

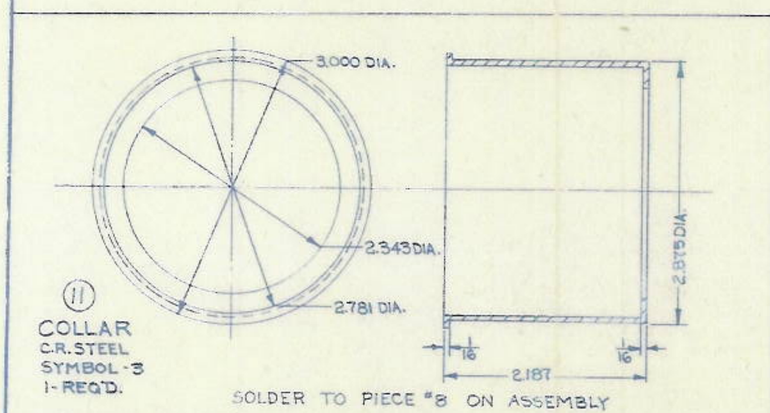
NAVAL RESEARCH LABORATORY WASHINGTON 20, D. C.	SCALE FULL DR'WN. W. Blodgett	TYPE - CXR-3 RECEIVER	
BLDG. 30 — PHONE 54	CH'K'D.		PLATE 6
ROOM 4 — DATE 10-20-44	APPR'VD.	UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ± .005	SHEET 1 OF 2

DECLASSIFIED









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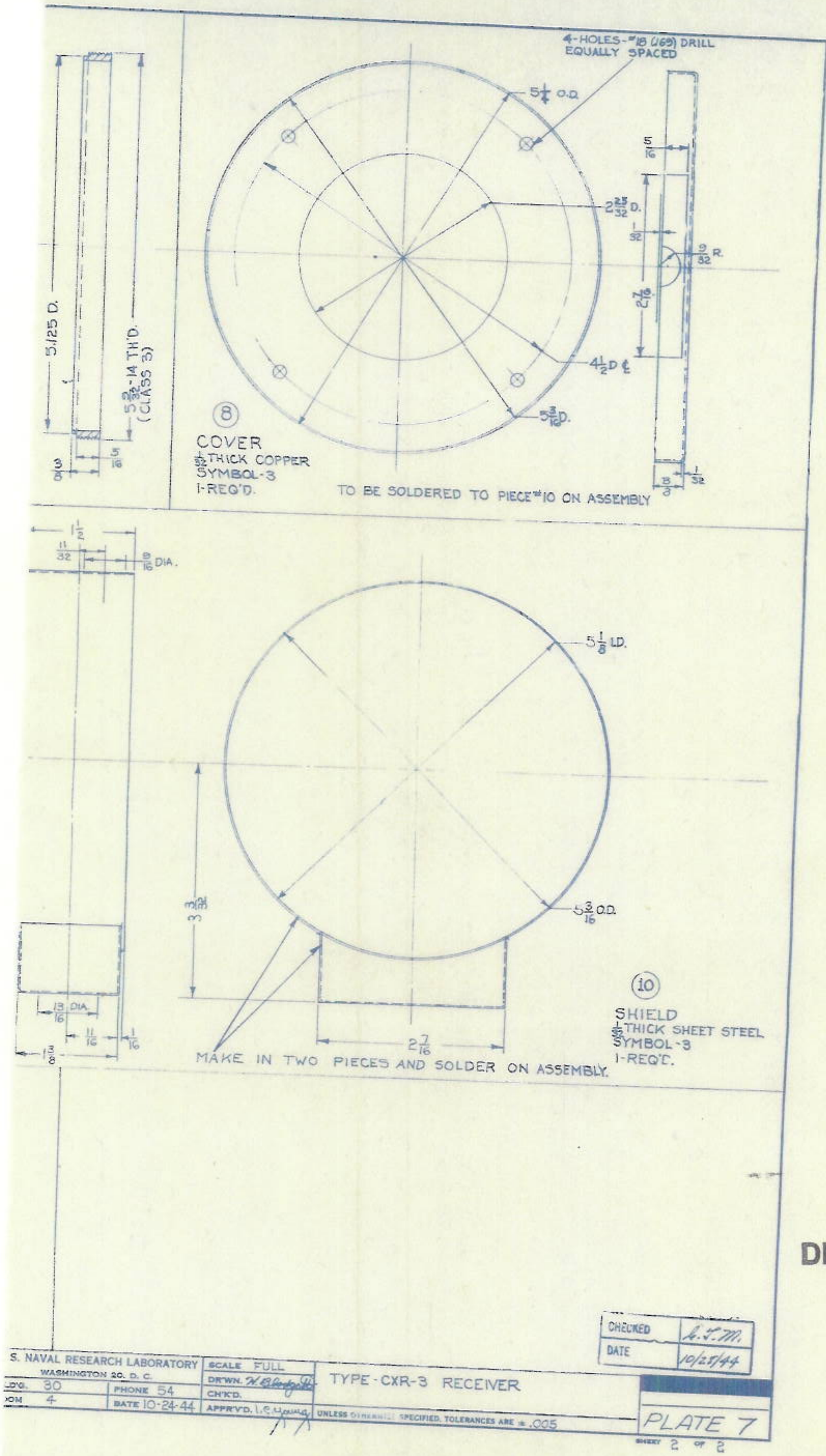

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