25 July 1939

NRL Report No. M-1547

FR-1547

NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report on

The Fogging of Photographic Materials

by

Radiographic Radium

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text - 5 Tables - 5 Plates - 2

Authorization: BuEng. let. JJ46-11/L5(7-5-Ds) of July 7, 1939.

Date of Work: July 7, 1939 - July 19, 1939.

Prepared by:

Herman F. Kaiser, Jr. Physicist

Reviewed by:

R. H. Canfield, Sr. Physicist, Supt. Division of Physical Metallurgy

Approved by:

H. M. Cooley, Captain, USN, Director

Distribution:
BuEng. (5)
BuC&R (5)

bms

TABLE OF CONTENTS

APPENDICES

ABSTRACT

A variety of commercial photographic and x-ray films were exposed under conditions simulating actual shipping conditions at several distances from a standard 250 milligram radium capsule enclosed in its lead carrying case. The exposures required in each case to produce a density gain of 0.07 were determined and a table was constructed giving the permissible transit times for each kind of film when 15 feet from the radium unit. These values are at the least several times those permitted for the same conditions by present railway express regulations.

AUTHORIZATION

1. The studies of the fogging of various grades of commercial photographic films by a typical 250 milligram radium unit were authorized by Bureau of Engineering letter JJ46-11/L5 (7-5-Ds) of 7 July 1939.

STATEMENT OF PROBLEM

2. The object of this problem was to establish experimentally those conditions under which photographic material of various commercial grades will be seriously damaged by fogging due to their proximity to a radiographic radium unit enclosed in its lead carrier case as for shipment. It has been requested that these experimental tests be not too elaborate or extensive but sufficient to give support to some calculations made on the basis of some allied facts.

KNOWN FACTS BEARING ON THE PROBLEM

3. On 1 May 1939 the Railway Express Agency, Inc., 230 Park Avenue, New York, N. Y., issued a set of regulations stipulating the conditions under which radium in quantities up to 100 milligrams would be accepted for shipment by express. It was understood that amounts in excess of 100 milligrams would not be acceptable. The stated conditions are given in Appendix I(a).

4. A conference was held between representatives of the Railway Express Company and representatives of the Bureau of Engineering and the Bureau of Construction and Repair, in which the Railway Express Company agreed to accept radium shipments in amounts up to 300 milligrams provided that these were shipped under certain stipulated conditions which are given in Appendix I(b).

5. These conditions imposed serious limitations on the shipping of Naval radiographic radium units of 250 milligram strength. With the two-inch lead protection in these units, the time of maximum allowable transit time is 18 hours. For trans-continental shipment in single passage requiring about 90 hours, a protective thickness of over three inches of lead is demanded. This additional lead protection will more than triple the shipping weight of the 250 milligram unit at present about 185 pounds in weight.

6. From experience gained in the use of radium in radiographing steel of various thickness, it seemed that these allowed transit times were considerably shorter than they should be. The standard radiography exposure charts developed at the Naval Research Laboratory indicate that for a thickness of three inches of steel (equivalent to two inches of lead) an exposure time of five days will be required when using a 100 milligram source four feet from the film cassette containing Eastman x-ray film with lead intensifying screens, the resulting photographic density being 1.6. On this basis it may be estimated

(taking the intensification factor of lead screens equal to 1.8) that an exposure of 86.4 hours will be required using a 250 milligram source and no intensifying screens at the same distance as before 4 feet. At 15 feet (the minimum distance allowed by the Express Company regulations for sensitive films) the exposure time should be $15^2/4^2$ times as great or 1215 hours to produce a density of 1.6.

7. The above estimate gives the number of hours required at a distance of 15 feet from a closed 250 milligram radium unit to produce a blackening density of 1.6. To further estimate the length of time to produce a small density of say 0.07 (which can be conveniently accepted as a tolerable fog density) it is necessary to make the assumption that the initial rate of blackening is approximately the whole time average or 1.6/1215 and that this rate of blackening is linear. This is fairly justified because it is known in photography that at low densities the blackening does not follow the logarithmic blackening law D = log I t but instead is linear with time and that this rate of blackening is far smaller than what may be deduced from the log plot. Accordingly, we estimate that an exposure time of $\frac{0.07}{1.6/1215}$ = 54 hours approximately will be required to produce a tolerance fog of 0.07 density on Eastman Duplitized X-ray film.

8. Using the time 54 hours for 15 feet from a 250 milligram unit as the basic tolerance time, Table 1 has been computed giving the number of hours permissible transit time for various amounts of radium from 100 to 500 milligrams protected with lead thicknesses from 2 to 3-1/2 inches, photographic material being at a distance of 15 feet.

9. A comparison of the figures in Table 1 with corresponding figures in the Railway Express Company table in Appendix I(b) will show that these computed times are roughly three times as great as those actually permitted. Because of this divergence it was thought best to make direct experimental tests to determine which set of figures can be substantiated.

TEST METHODS

10. A selection of typical commercial photographic films including slow, fast, extra fast and x-ray films was purchased from fresh stock. Table 2 lists the kinds of film (5" x 7" size only) used.

11. To simulate actual shipping conditions as far as possible, it was thought best to expose these films to the standard radium carrier unit in their own cartons wrapped as by the manufacturer rather than to use special cassettes such as radiographic film holders. Accordingly, a box of each kind of films was opened in total darkness, all but two or three of the films were removed and placed in a marked storage box, the remaining two or three films were then rewrapped as before. Two boxes of each kind of film were then

prepared. In addition to these exposure boxes, two types of special cassettes were included, one being a usual Eastman 5 x 7 X-ray exposure holder containing two x-ray U.S. films between three lead intensifying screens as for gamma radiography, the other being a similar cassette but containing no internal intensifying screens with two enclosed films. On the outside was fastened a 1/16" lead sheet with an x-shaped aperture at the center which thus partially shields the enclosed films.

12. The tests were performed in a laboratory room of fair size with concrete walls and floor. The 250 milligram radium carrier-unit was placed on the floor at a point near one corner of the room. From this point circles wwith various radii (3, 6, 9, and 15 feet) were laid off with chalk on the floor and the exposure boxes and cassettes were set up on these. Two test runs of 72 hours duration were made. In the first, the films were placed at distances of 9 and 15 feet; in the second, at 3 and 6 feet.

13. After each run the exposed films were developed in total darkness. An attempt was made first to use a single develper on all the different kinds of films, but it was found better to use different developers appropriate to the kind of film and developing normally. In developing, one unexposed film from the stock box was developed with each pair of exposed films of any kind to furnish a blank or comparison film. The x-ray films in the special cassettes were developed in x-ray developer as in radiographic practice.

14. After fixing, washing and drying, the films were placed in a densitometer and their densities were determined as closely as possible. Two density determinations were made on each film. The data obtained are given in Tables 3 and 4.

15. In Tables 3 and 4, each recorded density is the mean of two or more determinations. Repeated readings on a given film usually agreed to 0.02 or better. The densitometer used was set so that it gave a zero reading on an unexposed Process film, which possesses the smallest background density. The gain in density of any exposed film was obtained by subtracting the background density of the unexposed blank from the observed density. These density gains listed in the tables are the data by which the fogging effect of the gamma radiation may be determined.

<u>DISCUSSION OF DATA OBTAINED</u>

16. The observed density gains for the exposed films were plotted in two graphs (Figures 1 and 2) in which density gain is plotted against the corresponding exposure expressed in milligram-feet hours, a lead thickness of two inches being understood. On each graph is a horizontal line at the density ordinate of 0.07 which has been taken as a tolerable density increase. The four sets of exposures have exposure values of 80, 220, 500 and 2000 milligram-feet

hours. An attempt was made to plot the data on a single sheet plotting density against exposure on a logarithmic scale, but this gave rapidly rising curves, while for the present study, curves approximately linear are desired. Therefore, two graphs were constructed, one covering the range 80 to 500 milligram-feet hours, the other the range 220-2000 milligram-feet hours. In each graph the points of intersection of the curve for each particular film with the horizontal 0.08 ordinate are marked. The tolerance exposures corresponding to each of these intersections are listed in Table 5, together with the corresponding permissible exposure times in hours at fifteen feet from the radium unit.

17. In the graph of Figure 1, a straight line has been drawn representing the expected increase of density with exposure upon whichh Table 1 has been computed. It is quote evident that the assumed rate of increase of density was about twice as great as is actually observed, so that figures of Table 1 may even be doubled safely. Only when x-ray films are used with lead intensifying screens does the rate of blackening equal that assumed in Table 1.

18. It may be noted from Figure 1 and Table 5 that the majority of the commercial films have very low blackening rates, and that even the fastest commercial photographic films have a much lower rate of blackening than the x-ray films. In view of the fact that the x-ray films have a high initial density around 0.20, the added blackening of 0.07 is only a fractional increase of the background density, while in the case of the other films it corresponds about to a doubling or tripling of the background density.

19. Various criteria may be advanced to determine when a particular film has received enough fog density to render it unfit for practical use, but the arbitrary density increase here adopted (0.07) seems to be conservative enough in view of the fog levels adopted in Federal specifications for photographic material. It is understood at present that in the 1940 General Schedule of Supplies the permitted fog levels will be as follows: Process Film 0.07; Slow films (such as Commercial) 0.12, Fast Films (such as S.S. Panchromatic) 0.15. All of these figures are greater than the here observed zero background plus 0.07 allowed for radiation fogging. The choice of the figure 0.07 is thus fully justified.

CONCLUSIONS

20. The increase in photographic density caused by gamma radiation from a standard 250 mg. capsule enclosed in its carrying case with two inches of lead protection has been determined experimentally for a variety of commercial films placed at several distances from the radium unit. These density increases for three day exposures are small for all kinds of films tested at 15 feet distance and enclosed in their commercial cartons.

21. From the density-exposure graphs for these materials, the exposure necessary to increase the density by 0.07 has been determined for each kind of film tested. All of these exposures are several times those permitted by the Railway Express Company shipping regulations for equivalent conditions.

22. The density exposure graphs show that the estimated allowable hours of transit given by Table 1 give an exposure which is less than any that is required to produce a density increase of 0.07 in any case here studied, and furthermore the figures of Table 1 can be safely doubled or those of the table of appendix I(b) be multiplied by six.

RECOMMENDATIONS

23. It is recommended that Table 1 be adopted as a very conservative working basis for determining allowable times of transit in shipping Naval radium units.

Table 1

Estimated Hours of Permissible Transit Time with Photographic Material Kept at a Distance of 15 Feet

Quantity of Radium	Thickness of Lead - Inches			
	2	2-1/2	3	3-1/2
	Allowable hours in transit			
100	134	199	372	681
200	67	99	186	341
250	54	80	149	272
300	45	66	124	223
400	33	50	93	170
500	27	40	74	136

Table 2

Photographic Film Material Used in These Tests *

Name	Batch No.	Date of Expiration
Process	P 6106-50-1	March 1940
Commercial	Q 6124-63-1	January 1940
Commercial Ortho	P 6107-4-5	July 1940
Supersensitive Panchromatic	V 6116-431-17J	June 1940
Ortho-X	H 6145-4-3	June 1940
Tri-X-Pan	A 6143-3-4J	June 1940
No screen x-ray	L 5133-304-600	March 1940
Ultra-Sensitive X-ray	XX 5120-646-400	July 1940

*Manufacturer, Eastman Kodak Company, Rochester, N. Y.

Table 3

Densities of Films, First Test Run

Kind of Film	Density Unexposed	Exposed at 15 ft.	Density Gain at 15 ft.	Exposed at 9 ft.	Density Gain at 9 ft.
Process (Dev. D-72)	0.00	0.02	0.02	0.02	0.02
Commercial (D-72 Dev.)	0.06	0.05	0.00	0.05	0.00
Commercial Ortho (D-72 Dev.)	0.05	0.06	0.01	0.07	0.02
Super-Sensitive Panchromatic (DK-60a Dev.)	0.08	0.08	0.00	0.09	0.01
Ortho-X (Constant Gamma Dev.)	0.03	0.04	0.01	0.07	0.04
Tri-X Pan. (Constant Gamma Dev.)	0.04	0.04	0.00	0.07	0.03
No Screen X-Ray (DK-60a Dev.)	0.09	0.13	0.04	0.24	0.13
X-Ray U.S. (DK-60a Dev.)	0.24	0.29	0.05	0.33	0.09
X-Ray U.S. with Pb Intensifier (X-ray Dev.)	0.17	0.25	0.08	0.53	0.36

Table 4

Densities of Films, Second Test Run

Kind of Film and Developer	Density Unexposedd	Exposed at 6 ft.	Density Gain at 6 ft.	Exposed at 3 ft.	Density Gain at 3 ft.
Process (D-72 Dev.)	0.00	.025	0.025	0.10	0.10
Commercial (D-72 Dev.)	0.06	0.18	0.12	0.27	0.21
Commercial Ortho (D-72 Dev.)	0.03_5	0.16	0.12_5	0.25	0.21_5
Super Sensitive Panchromatic (D-72 Dev.)	0.09	0.15_5	0.06_5	0.25_5	0.16_5
Ortho-X (DK-60a Dev.)	0.09	0.19_5	0.10_5	0.45_5	0.36_5
Tri-X Pan. (DK-60a Dev.)	0.10_5	0.27	0.16_5	0.46	0.35_5
No Screen X-Ray (DK-60a Dev.)	0.08	0.37_5	0.29_5	0.91_5	0.83_5
X-Ray Ultra Speed (DK-60a Dev.)	0.20_5	0.47	0.26_5	1.00	0.79_5
X-Ray U.S. with lead intensifiers (X-Ray Dev.)	0.20	0.53	0.33	1.47	1.27

Table 5

Tolerance Exposures Giving a Density Increase of 0.07 for the Various Film Materials Studied

Kind of Film	Tolerance Exp. in Mg. Ft. Hrs.	Allowable Transit Time at 15 ft. from 250 mg. unit
Process	1500	1350 hrs.
Super-Sensitive Pan.	525	473
Commercial	385	347
Com. Ortho	355	320
Ortho-X	355	320
Tri-X Pan.	305	275
X-ray U. S.	150	135
No Screen X -Ray	127	114
X-ray U.S. in Radiography Cassette	65	59

Appendix I(a)

COPY

RAILWAY EXPRESS AGENCY INCORPORATED
TRAFFIC DEPARTMENT
230 Park Avenue
New York

Effective May 1, 1939, shipments of Radium in quantities of 100 milligrams or less will be accepted only when encased in lead in accordance with the table set forth below.

Approximate time in transit, in hours, for indicated quantities of Radium, in designated thicknesses of lead, with a minimum distance to ordinary film of 10 feet, or to X-Ray film of 15 feet.

Quantity of Radium Milligrams	THICKNESS OF LEAD - INCHES 1/4	1/2	1	1-1/2	2	2-1/2	3
	Allowable hours in transit.						
Under 15 mg.	40	60	110				
15 mg and under 25	20	30	55	110			
25 mg and under 35	14	20	36	73	146		
35 mg and under 45	10	15	28	55	110		
45 mg and under 55		12	22	44	88	170	
55 mg and under 65		10	18	36	73	142	
65 mg and under 75			16	31	63	122	
75 mg and under 85			14	27	55	106	
85 mg and under 95			12	24	48	95	
95 mg to 100 incl			11	22	44	85	170
#Minimum weights of lead, pounds	1/2	3/4	3-1/4	9-1/4	19-1/2	36	58-1/2

#Approximate weights computed from spheres with sperical cavities 1/2 inch in diameter in each case. When cavities are of greater dimension, container weights will necessarily exceed the minimums quoted.

Shipments must have labels affixed thereto bearing the word RADIUM and the quantity of Radium, in milligrams, and thickness of lead, in inches.

RADON-Will be handled accordingly. Labels must show the EQUIVALENT RADIUM content, in milligrams, and lead thickness, in inches.

Appendix I(b)

Quantity of Radium	Thickness of Lead - Inches: 1	1-1/2	2	2-1/2	3	3-1/2
	Allowable hours in transit					
100 mg	11	22	44	85	170	
200 mg		11	22	43	86	172
300 mg			14	28	56	112

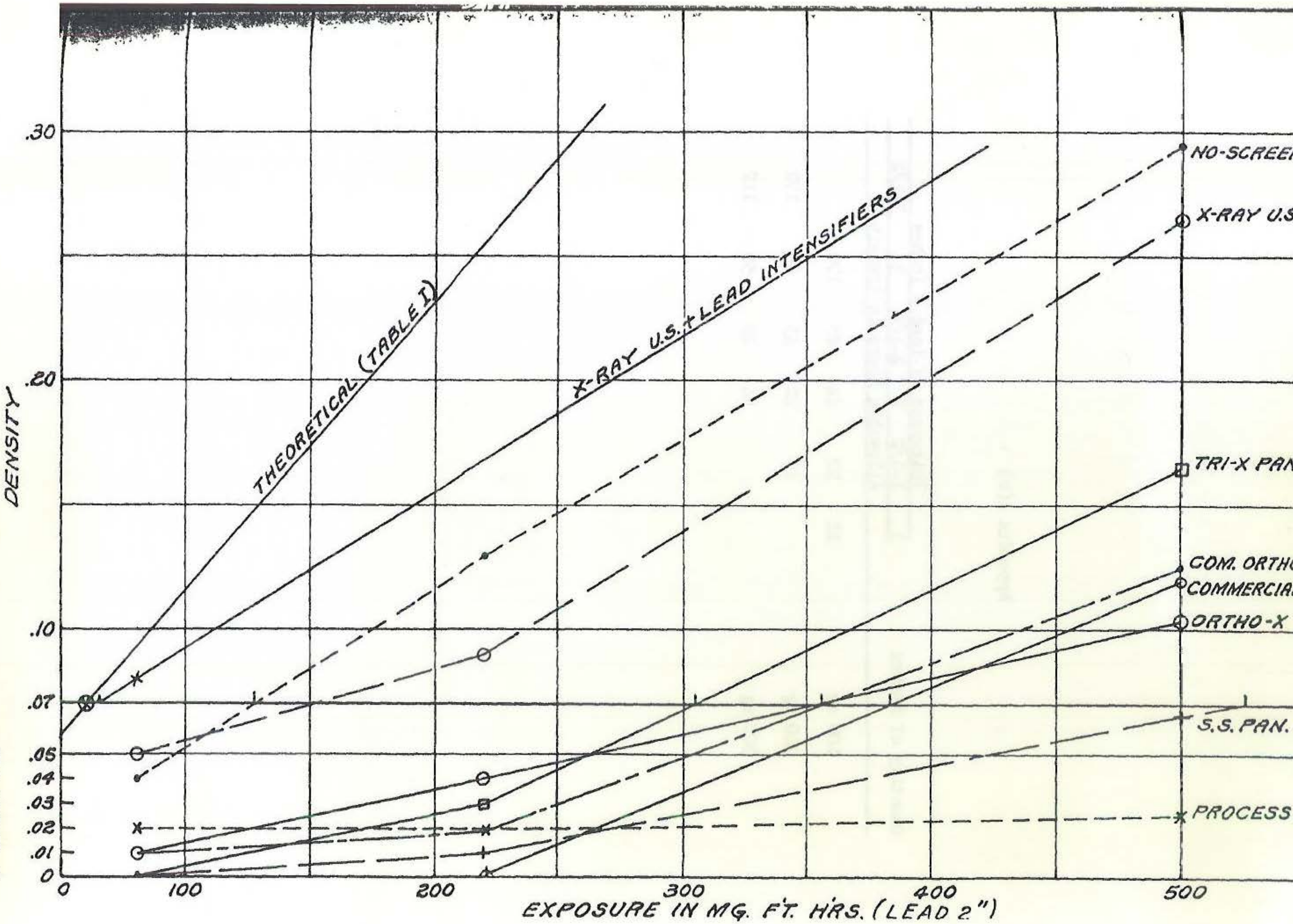
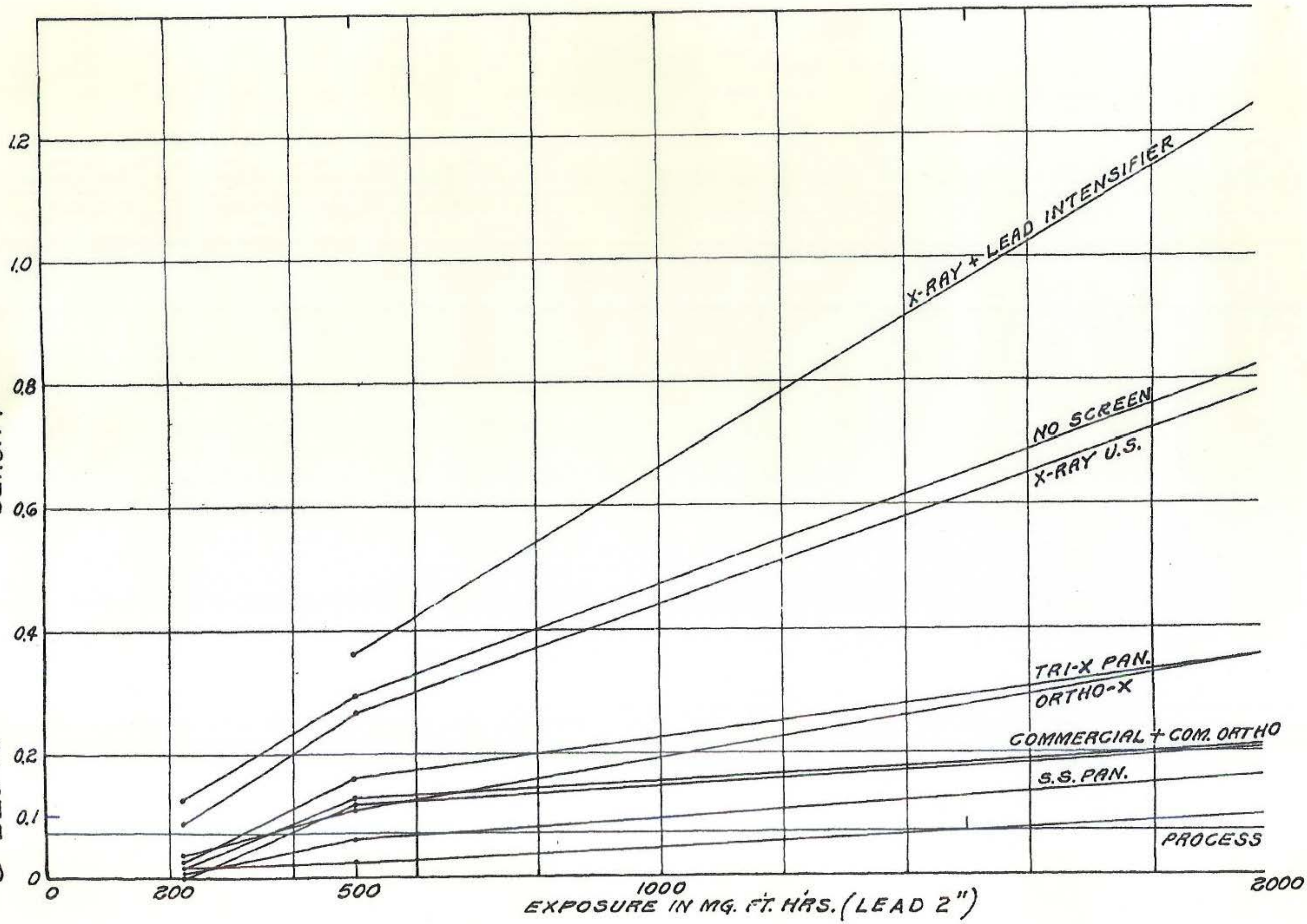

DENSITY
.30
.20
.10
.07
.05
.04
.03
.02
.01
0
0
100
200
300
400
500
EXPOSURE IN MG. FT. HRS. (LEAD 2")
THEORETICAL (TABLE I)
X-RAY U.S. + LEAD INTENSIFIERS
NO-SCREEN
X-RAY U.S.
TRI-X PAN.
COM. ORTHO
COMMERCIAL
ORTHO-X
S.S. PAN.
PROCESS

PLATE I



X-RAY + LEAD INTENSIFIER
NO SCREEN
X-RAY U.S.
TRI-X PAN.
ORTHO-X
COMMERCIAL + COM. ORTHO
S.S. PAN.
PROCESS
DENSITY
1.2
1.0
0.8
0.6
0.4
0.2
0.1
0
0
200
500
1000
2000
EXPOSURE IN MG. FT. HRS. (LEAD 2")

PLATE 2