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SSC-110

THE INVESTIGATION OF RADIOISOTOPES FOR THE INSPECTION OF SHIP WELDS

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SHIP STRUCTURE COMMITTEE

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February 28, 1958

Dear Sir:

As part of its research program related to the fabrication of hull structure of ships, the Ship Structure Committee is sponsoring a flaw-detection study at the Naval Ordnance Laboratory. Herewith is a copy of SSC-110, First Progress Report on "The Investigation of Radioisotopes for the Inspection of Ship Structures", by E. L. Criscuolo, D. P. Case and D. Polansky.

This project has been conducted under the advisory guidance of the Flaw Detection Advisory Group of the Ship Structure Subcommittee.

Distribution of this report is being made to those individuals and agencies associated with and interested in the work of the Ship Structure Committee. Any questions, comments, criticism or other matters pertaining to the report should be addressed to the Secretary, Ship Structure Committee.

Yours sincerely,

K K Cowart

K. K. Cowart
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure
Committee

Serial No. SSC-110

First Progress Report
of
Project SR-127

to the

SHIP STRUCTURE COMMITTEE

on

THE INVESTIGATION OF RADIOISOTOPES FOR THE INSPECTION OF SHIP WELDS

by

E. L. Criscuolo, D. P. Case and D. Polansky

Naval Ordnance Laboratory
White Oak, Maryland

under

Department of the Navy
Bureau of Ships Project Order 92703
BuShips Index No. NS-021-201

Washington, D. C.
National Academy of Sciences-National Research Council
February 28, 1958

THE INVESTIGATION OF RADIOISOTOPES FOR THE INSPECTION OF SHIP WELDS

ABSTRACT

A study was conducted that explored the potentialities of radioactive isotopes for the inspection of welds in ship structures. Various parameters were investigated to determine an optimum radiographic technique for the inspection of hull welds of 1/2- to 2-in. plate. Technique and sensitivity curves for thulium, iridium, cesium, and colbalt are included. For the inspection of welds in 1/2-in. to 1-in. thick plate, iridium is the most promising isotope. A portable exposure container for iridium has been developed.

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*F film with calcium tungstate screens

THE INVESTIGATION OF RADIOISOTOPES FOR THE INSPECTION OF SHIP WELDS

INTRODUCTION

Krieger, Wenk, and McMaster[1] have reviewed various nondestructive test methods for the inspection of welded joints in ship structures. One of their recommendations was to explore the potentialities of Iridium 192 and other isotopes as radiographic sources. Radiography is one test method that can locate in hull plate weld discontinuities that are frequently associated with the failure of ship and other engineering structures.

The use of radioactive material for industrial inspection is not new. As early as 1930 Mehl, Doan, and Barrett[2] reported on the use of radium gamma rays in radiography. High cost and scarcity prohibited widespread use of this natural radioactive material. The availability of artificially produced radioactive material since 1946-47 has revived the interest in radiography with gamma rays. These radioactive isotopes have the advantages of low cost, availability, and choice of energy range*. Numerous investigations[3--7] have studied these isotopes as radiographic tools.

The present work explores the use of radioactive isotopes for inspection of ship welds. The available radioactive sources, film, screens, and techniques are being tried to determine an optimum radiographic technique

*Several of the terms used in this report are described in the Glossary, Appendix A.

for the inspection of hull welds of 1/2- to 1-in. plate. Although the thicknesses mentioned are of primary interest, data are also being compiled to cover a range of 1/2- to 2-in. of steel to anticipate any future demand. The bases for evaluation are: (1) inspection quality, (2) speed, (3) economy, and (4) safety of operation.

Until further information regarding the size and shape of a defect that may be considered harmful is made available, the two per cent sensitivity level is being used as a guide.

RADIOGRAPHIC METHOD

Radiography means recording an X-ray image on film. The object of interest is placed on the film and exposed to a source of radiation. Radiation is absorbed more by the thicker portions of the object so that a latent image is produced on the film by the unabsorbed X-rays. The absorption of the rays is a function of the kind of material as well as the thickness of the object and follows the classical absorption law

$$I = I_o e^{-\mu x}$$

where

I_o = radiation intensity in

I = radiation intensity out

μ = linear absorption coefficient of the material

x = thickness of material

If the thickness of the object varies because of a cavity or discontinuity, more radiation will penetrate that area and produce greater film blackening. Fig. 1 illustrates the basic arrangement for an exposure.

X-ray film differs from ordinary photographic film in that both sides of the film base are coated with photographic emulsion. The double coating increases the contrast and speed of the film for X-ray use. The emulsions, being relatively thin, absorb a very small percentage of the radiation falling upon them. Thus the film is commonly sandwiched between thin lead or chemical screens, which emit secondary radiation that boosts the radiation level on the film. Lead screens when exposed to X or gamma rays produce photoelectrons, which are easily absorbed by the film to produce greater film blackening. Lead screens generally increase the effective film speed by a factor of 2 or 3. Chemical or salt screens give off light as well as electrons when hit by radiation, and the increase in film speed is usually by a factor of 20 or 30. The large crystal size of the salt screen unfortunately causes a reduction in image sharpness on the film.

A lead filter is placed between the film and object to minimize the effects of scattered radiation. Depending upon the source and physical arrangement, the thickness of this filter can range from .030 to 0.250 in.

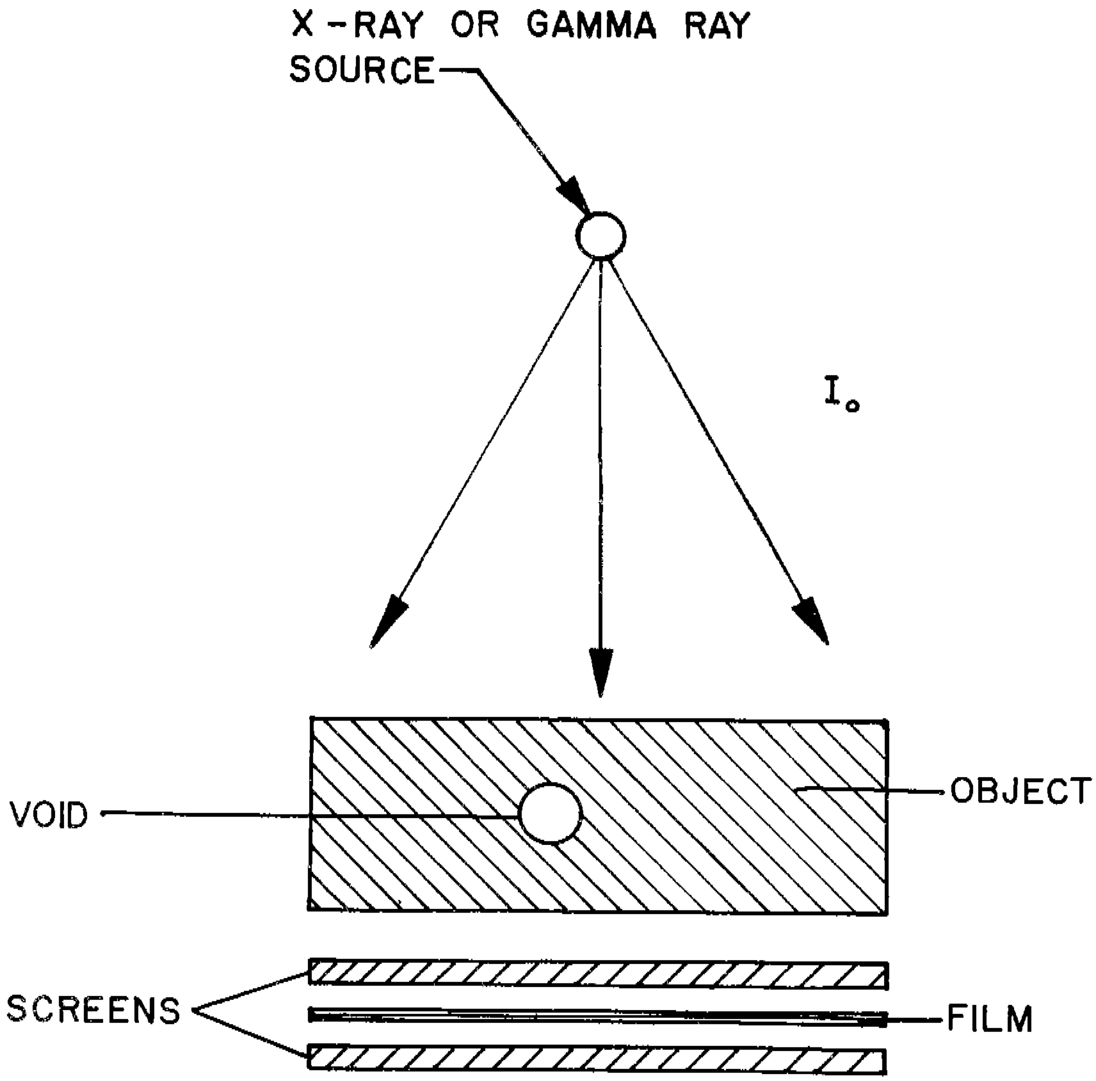

Fig. 1. Exposure arrangement

RADIATION SOURCES

Two basic types of sources are available for commercial radiography--the X-ray generator and the radioisotope. The X-ray generator converts electrical energy to X-ray energy. The radioisotope is a material that produces gamma rays continuously and without any external power source. Radium is an expensive natural source which has been utilized for many years. The artificially produced radioisotopes are relatively new and are available in a range of energies at moderate cost. They have a much shorter half life than radium and must therefore be replaced at regular intervals.

Although a large number of radioisotopes have been explored for industrial radiography, only the most promising ones are considered in this investigation. These are the radioactive isotopes of: thulium (Tm 170), iridium (Ir 192), cesium (Cs 137) and cobalt (Co 60). Radium (Ra 226) is included for comparison.

Tm 170 is not generally available in this country but can be obtained from Canada. It is a low-energy radioactive source of low output and low specific activity. It has a half life of 127 days, and its output is 0.045 roentgens per hour at one meter for one curie. The Tm 170 gamma-ray spectrum contains one predominant line of .083 MeV. There is some disagreement on the other gamma lines. Some report no other gamma lines while Grant and Richmond[8] report .083, .205, and .430 MeV lines. Graham and Tomlin[9] report a line between 0.400 and 0.500 MeV which is probably due to bremsstrahlung. While there is some uncertainty as to the exact spectrum, it is evident from the absorption data by Halmshaw[10] that the high-energy lines exist. Tm 170 decays and produces beta lines at 0.884 MeV and at 0.968 MeV; the former leads to ytterbium (Yb 170) and produces gamma rays during the decay.

Ir 192 is probably the most widely used low-energy source. Its spectrum is composed of several gamma lines: .200, .295, .307, .315, .457, .589, and .606 MeV[11]. The .315 and .457 lines are the most intense. While the half life of this source is short (74 days), this disadvantage is partially offset by the fact that it is inexpensive and easily obtainable. Another important characteristic is the radiation output of .51 roentgens per hour at one meter. Ir 192 also has a high specific activity, which results in small physical size for given radiation intensity. Its small size and low energy make it very useful for radiography.

Another radioisotope that has been used for industrial radiography is Cs 137. This isotope has a single gamma line at .66 MeV, is produced as a byproduct of other fission processes, and is easily obtainable. Some of the disadvantages of Cs 137 are the low specific activity and low output. A curie of this source puts out 0.39 roentgens per hour at one meter. The desirable characteristics of this source are the large half life (37 years) and medium energy.

The most popular industrial source is Co 60. It has an average energy of 1.2 MeV, a half life of 5.3 years, and high specific activity. Cobalt has thus displaced radium in many applications.

Before artificial radioisotopes became available, radium was used extensively for industrial radiography. The average energy is considered to be 1.7 MeV. It has a half life of 1690 years and an output of 0.84 roentgens per hour at one meter. Thus source may be purchased for approximately $15,000 per gram. Where a supply already exists, it is still used for inspection.

Table 1 summarizes the characterics of the common radioisotopes included in this study. Those listed herein are not all the isotopes used in radiography.

TABLE 1

CHARACTERISTICS OF ISOTOPES INCLUDED IN THIS STUDY

	Tm^{170}	Ir^{192}	Cs^{137}	Co^{60}	Ra^{226}
Average Energy (MeV)	.083	.28	.66	1.2	1.7
Production Process	Pile Produced	Pile Produced	Fission Product	Pile Pro-duced	Mined and Refined
Half Life	125 days	74 days	37 years	5.3 years	1590 years
HVL* Lead (inches)	--	.80	.39	.47	.51
HVL* Fe	.42	.52	.67	.75	.80
Radiation output rhm/curie	45×10^{-3}	0.51	0.39	1.32	0.84

*Measured value broad beam

In this report only the experimental results from thulium, iridium, cesium, cobalt, and radium are reported. From data presented in the literature, these sources appear the most promising. Table 2 lists the measured focal-spot size and the radiation output at one meter. The differences in the output readings given in Tables 1 and 2 are probably due to self absorption. An example of this is thulium, which has a very low energy and a high atomic number. The measured output for a 45-curie source is .230 roentgens per hour at one meter; whereas the calculated output is 2.08 roentgens per hour at one meter.

TABLE 2

RADIATION OUTPUT AND SOURCE SIZE OF THE ISOTOPES STUDIED

Source	Curies	Measured Radiation Output rhm	Measured Focal Spot mm
Tm^{170}	45	0.230	7.0
Ir^{192}	2.5	1.680	2.0
Cs^{137}(evaporated)	2.0	0.780	10.0*
Co^{60}	1.06	1.440	2.0
Ra^{226}	1.0 gm	0.83	10.0 aprox.

*Pelleted Cs^{137} sources which have a smaller physical size are now available.

Another important characteristic of sources is the physical size or what is commonly known as focal-spot size. Large source size will cause large geometrical unsharpness which in turn results in a poor image quality. Fig. 2 shows the focal spots produced by pinhole projection and X-ray radiographs of the thulium, iridium and cesium sources. Iridium has the smallest spot of 1.7-mm diameter. There is good correlation between the size of a focal-spot image and the actual size of the source as measured on the radiograph. The pinhole projection was made by placing the source on one side and the film on the other side of a piece of lead containing a small pinhole. The lead was equidistant from the source and film. The rays pass through the hole so as to produce an image of the source that is a direct measure of the source size. The radiograph of the source was made by a very short exposure from an X-ray machine.

TECHNIQUE AND SENSITIVITY

A modified absorption curve can be used to describe radiographic technique. The exposure factor is plotted on a log scale as the ordinate, and the thickness of material on a linear scale as the abscissa for a given film density. For convenience the term exposure factor is defined, as suggested by Morrison[4], as the milliroentgen/hr at one meter multiplied by exposure time in minutes divided by the source-film distance in inches squared. This definition makes it convenient to use these curves for a particular source or any source-film distance.

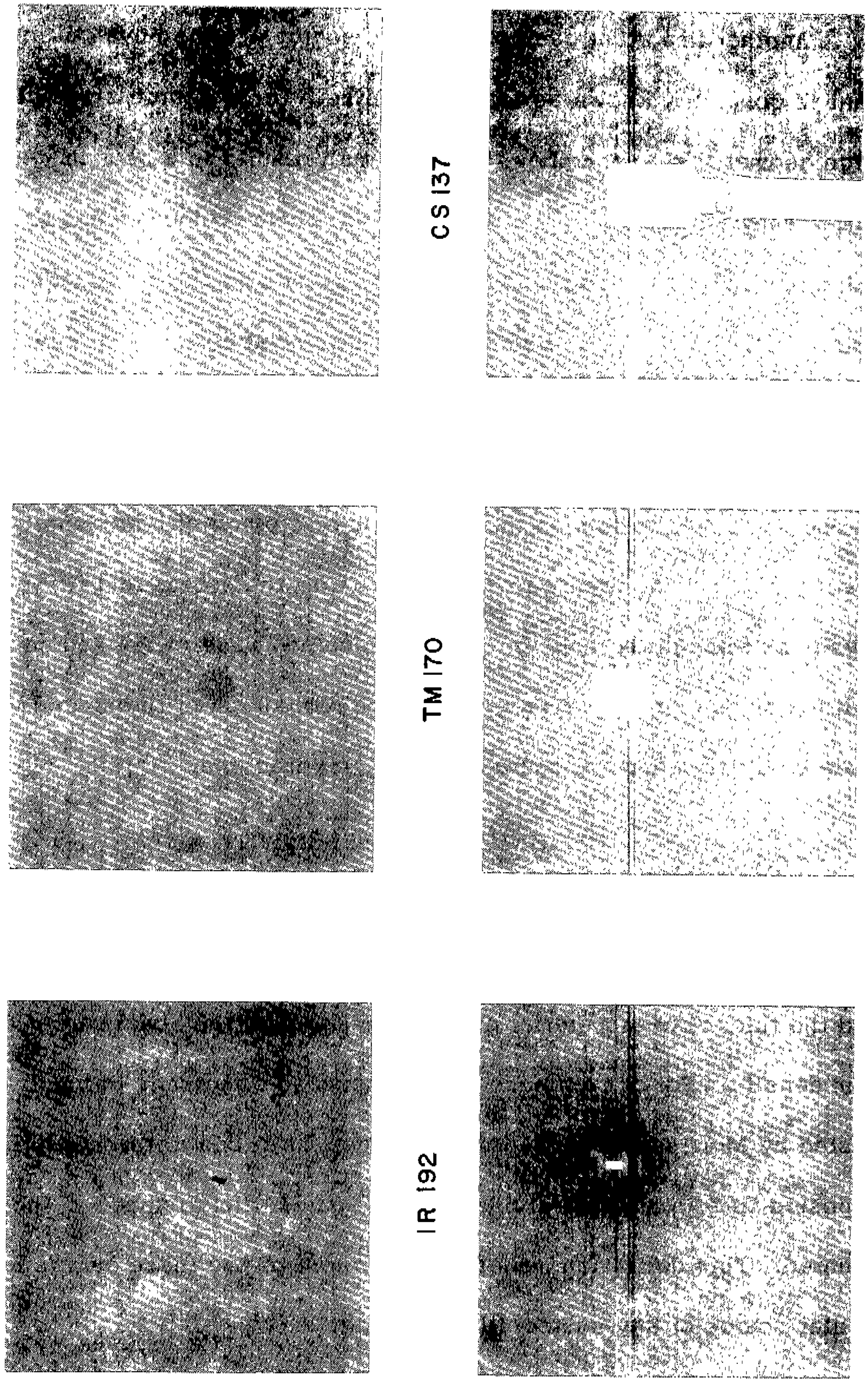

Fig. 2. Pinhole projection of focal spots

A family of curves will develop for various densities. As a result, if one knows the desired density, material and thickness, the proper exposure factor can be determined.

Sensitivity is not mentioned in any of these methods. Johns and Garrett(12) showed graphically the relationship between sensitivity (as a function of thickness) and exposure factor. This relationship resulted in a family of loops defining the thickness and exposure ranges for a given sensitivity. A combination(6) of the technique and sensitivity curves results in charts 1--30. The area inside the dotted lines defines the conditions that will give the sensitivity of that loop. The solid lines are the technique lines for a given density. These two families of curves give the radiographer all the information necessary to produce a good radiograph.

EXPERIMENTAL TECHNIQUE AND SENSITIVITY DATA

During the course of this work several sources, such as 45 curies of Th 170, 2 and 4 curies of Ir 192 and 2 curies of Cs 137, were investigated. The Co 60 source already on hand at the laboratory was utilized for these experiments. Comparison of the value of these sources was made by means of technique and sensitivity curves. All the necessary data to draw these curves were obtained by one of two methods. For the first method a flat plate of a given thickness, with penetrameters placed on its surface is radiographed to a given density. By changing the exposure so that several densities are obtained, enough data are produced to plot these curves. The second method, which is described by Johns and Garrett[12], is much faster. This method consists of radiographing a tapered wedge that contains a family of milled slots, each of which represents a fixed percentage of the wedge thickness. By reading along the radiograph to the point where the slot disappears, the limit of sensitivity can be determined. Results from these two methods compare faborably.

Charts 1 through 8 show the results obtained with Th 170 and various types* of film, such as M, A, F, and F with calcium tungstate screens, all with and without filters. These data were taken at a source-to-film distance of 18 in. Charts 9 to 18 show the results for Ir 192 obtained with the same combinations of film and filters as for Th 170. The technique and sensitivity curves for Cs 137 are illustrated in Charts 19 through 26. For completeness, the technique and sensitivity curves for Co 60, which had been obtained prior to the current investigation, are given in Charts 27 through 30 for type AA and A film, and for F film with calcium tungstate screens. The optimum conditions as obtained from these curves for 3/4-in. steel plate are given in Table 3. From these data it can be seen that Ir 192 is the most favorable source. Sensitivity of two per cent is attainable even with type F film, calcium tungstate screens, and lead filters.

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*Special features of each type of film are given in Table 4.

TABLE 3

COMPARISON OF TECHNIQUES FOR 3/4-IN. STEEL PLATE
Density 2.0

Film	Screen	Filter	Exposure Factor	Sensitivity (per cent)
THULIUM 170				
M	Pb	None	850	2
M	Pb	.030 Pb	2200	1
A	Pb	None	650	2
A	Pb	.030 Pb	1150	1
AA	Pb	None		
AA	Pb			
F	Pb	.030 Pb	250	2
F	calcium tungstate	.030 Pb	10	3
IRIDIUM 192				
M	Pb	None	500	2
M	Pb	.030 Pb	650	1
A	Pb	None	166	2
A	Pb	.030 Pb	116	1
AA	Pb	None	50	2
AA	Pb	.125 Pb	55	1
F	Pb	.030 Pb	65	2
F	calcium tungstate	.030 Pb	12	2
CESIUM 137				
M	Pb	None	300	2
M	Pb	.125 Pb	620	2
A	Pb	None	100	3
A	Pb	.125 Pb	180	2
AA	Pb	None	51	3
AA	Pb	.125 Pb	100	2
F	Pb	.125 Pb	80	3
F	calcium tungstate	.25 Pb	14	3
COBALT 60				
AA	Pb	None	86	3
A	Pb	None	155	3
F	Pb	0.25 Pb	185	4
F	calcium tungstate	0.25 Pb	12	3
RADIUM 226*				
A	Pb	None	160	4
F	Pb	None	160	4
F	calcium tungstate	0.25 Pb	25	4

*From Handbook of Radiology, NAVORD Report 3649

FILM DATA

All of the data were obtained on Eastman Kodak film; therefore, Table 4 is included so that a conversion of the film speed factors can be obtained for the various film manufacturers. A large part of this work was done with Eastman type A film; however, Eastman recently replaced type A with type AA, which has approximately twice the speed of type A. In order to supplement the data already obtained, it was necessary to determine the speed factor of the new film. The comparison of the characteristic curve for each of these films is illustrated in Charts 31 and 32 for 250 KV and 2 MeV. At 250 KV, AA film is approximately twice as fast as type A; whereas at 2 MeV the speed factor is 2.5 times that of A film. In order to compare the resolution of these films, technique and sensitivity curves were made for each.

TABLE 4

INDUSTRIAL X-RAY FILMS OF SIMILAR CHARACTERISTICS

Contrast	Grain	Speed	Ansco	DuPont	Eastman
High	Finest	Slow	Superay B	510	M
High	Very fine	Medium	Superay A	506	A
Medium	Fine	Fast	Superay C	508	K
Medium	Fine	Very fast*	High Speed	504	F

*When used with calcium tungstate screens.

RADIOGRAPHIC COMPARISONS

As a practical approach, radiographs were made of welded 3/4-in. steel plates with known defects. Permission was obtained from Committee E-7 of ASTM to use its library of welded plates upon which reference radiographs are based (E99-55T). A complete set of 35 radiographs of these plates has been made with iridium and cobalt. For comparison purposes only a few plates were radiographed with thulium and radium.

ISOTOPE HANDLING SYSTEM

In industrial radiography three safety conditions must be met. The first is proper storage when not in use. The source container must be so designed that the level of radiation is reduced to 10 milliroentgen/hr at one meter from the source. The second safety condition is operator protection. Apparatus must be designed so the maximum exposure received by the operator is negligible. The third safety condition is for the protection of other personnel who might be working in the area, particularly on the far side of the weld under inspection.

Many methods have been developed and devised to handle radioactive material for radiography. The simplest of these methods, which is practical only for low-strength sources, is the fish-pole system with a bare source. The source, which has a hook or string attached to it, is stored in a lead pot or container. The source is removed from the pot with a long rod and placed into position for radiography. A variation of this method of handling isotopes has the source permanently mounted in a lead cylinder or plug open at one end. The plug is stored in a lead pot and extracted by a long rod with the open end of the plug away from the operator. Larger-strength sources (up to approximately 2 curies of Co 60) can be handled in this manner. Another device has the source fixed in the pot. The exposure is made by opening the pot and exposing the source. In this type of device very large-strength sources may be used. In a more versatile system the source is guided from the pot to the exposure position through a flexible tube. While each of these handling methods has its own advantages and disadvantages, the safety problem of personnel working in the area is not considered. For the inspection of ship welds it is desirable to have a system where men can work safely in the immediate area where an exposure is being made.

An exposure fixture was therefore developed to hold 2 curies of iridium. This device is composed of a lead container with metal hood. The isotope is exposed by removing a lead plug. The hood has the following functions. it maintains a fixed source-to-film distance and serves as a radiation shield. The general layout and the radiation leakage pattern are shown in Fig. 3. The maximum radiation one meter from the surface is 4 mr/hr.

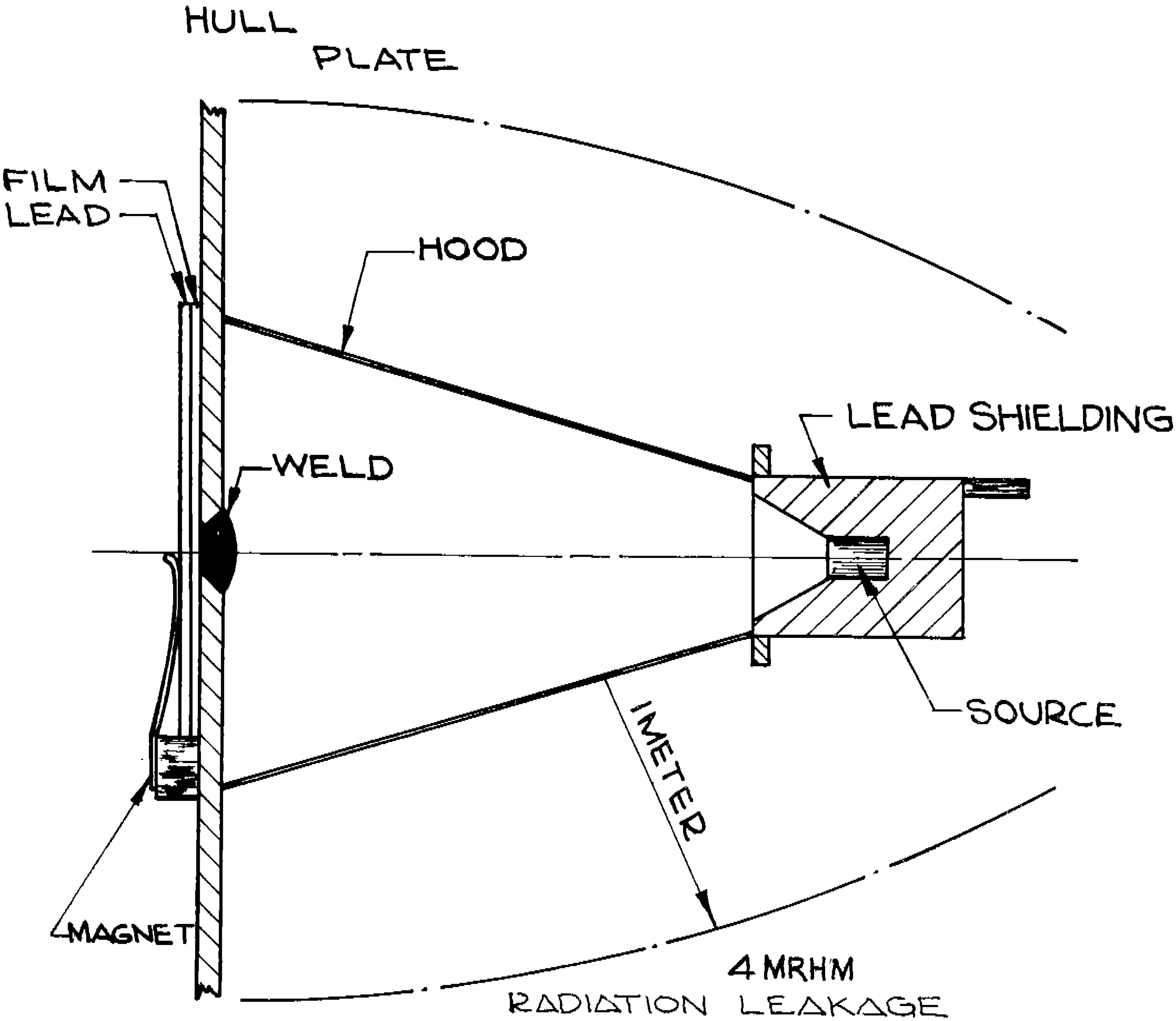


Fig. 3. Schematic arrangement of exposure container in use

In operation, the hood is placed on one side of a ship plate weld and film is placed on the other side. The exposure can be safely made when the personnel are within three feet of the device. Fig. 4 shows the exposure hood in use. This apparatus has been used successfully in the laboratory; but because it is recognized that laboratory and field conditions differ, arrangements will be made to have the apparatus field tested.

CONCLUSION

The numerous radioactive isotopes currently available provide a wide selection of gamma-ray energies. The results obtained in this study of the various isotopes indicate that the selection is directly related to the thickness range of steel to be inspected. A comparison of the technique with the isotopes is given in Fig. 5. These results are for a medium speed, medium grain film such as Eastman Kodak Type A for a film density of 2.5. These curves are drawn for the range where 2 per cent sensitivity is obtainable. The lower limit on each curve is indicated by a dot on the curves. Since the exposure factor is used as the ordinate, the comparison is independent of the source size.

With the exception of Cobalt 60, the lower thickness limit for thulium, iridium, and cesium is just below 1/2 in. of steel. Cobalt 60 has a lower limit of approximately 7/8 in. The exposure factor for

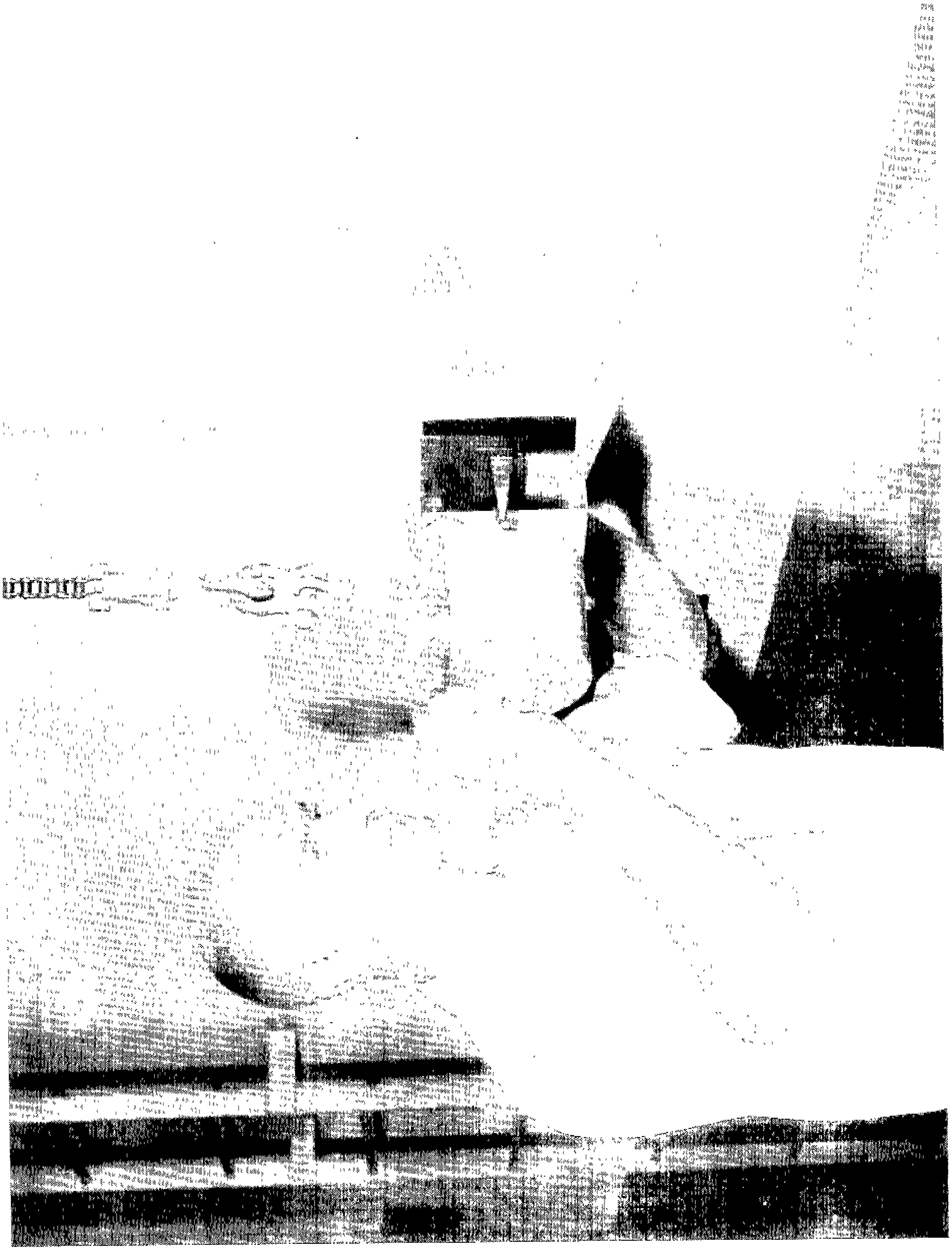


Fig. 4. Photograph of exposure container

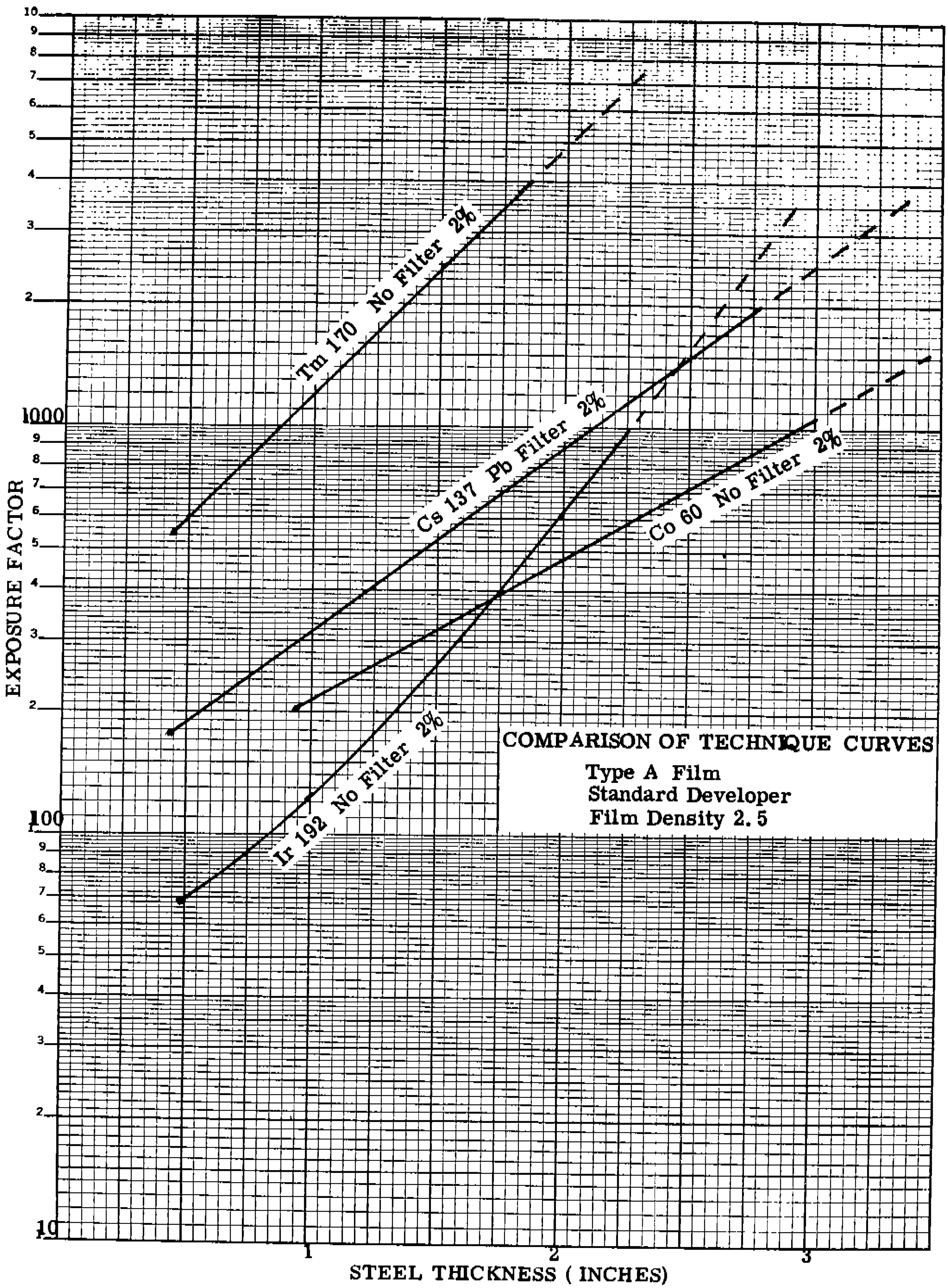


Fig. 5. Comparison of technique curves

iridium and cobalt is equal for a thickness of 1 3/4 in. Beyond this thickness the exposure factor for iridium compared to cobalt increases very rapidly. It is concluded from the data that the thickness range for iridium is 1/2 to 1 3/4 in. Cobalt is useful from one inch of steel to greater thicknesses. Cesium 137 may be used in place of Iridium 192 for the thickness range of 1/2 to 2 1/2 in. but with exposure times that for most thicknesses will be at least twice as long. Thulium in the range of 1/2 to 1 1/2 in. of steel will require exposures about ten times those of iridium. Since iridium permits the use of the lowest exposure factor in the inspection of steel in the thickness range from 1/2 to 1 in., it is recommended for the inspection of hull plate or 3/4-in. thick welds. Sensitivity of better than 2 per cent on 3/4-in. steel was obtained with the relatively short exposure of 12 minutes with a two-curie iridium source. Although many other isotopes can be used satisfactorily for the thickness range of 1/2 to 1 in., iridium produces a superior radiograph.

While the low energy of iridium is advantageous, its short half life is an inconvenience. This inconvenience can be overcome by careful timing in ordering replacement sources.

Iridium 192 can be shielded by small amounts of lead as it has relatively low energy.

Based on radiographic results, an exposure container was designed for two curies of iridium. This device shows that a practical fully shielded system can be built to protect operating and other personnel without restricting a large area. Further field tests of this unit are necessary to evaluate fully this system.

Further study on this project may be taken in the following directions:

1. Reduction of exposure time by film density intensification with chemical intensifiers or toners (e.g., DuPont intensifier).
2. Feasibility study of filmless methods.
3. Feasibility study to determine if low-density film can be electronically scanned and integrated to present picture on screen (Log-Etron is a device for scanning aerial negatives to reduce high densities and increase low densities. The scan is projected on another film which has to be developed).

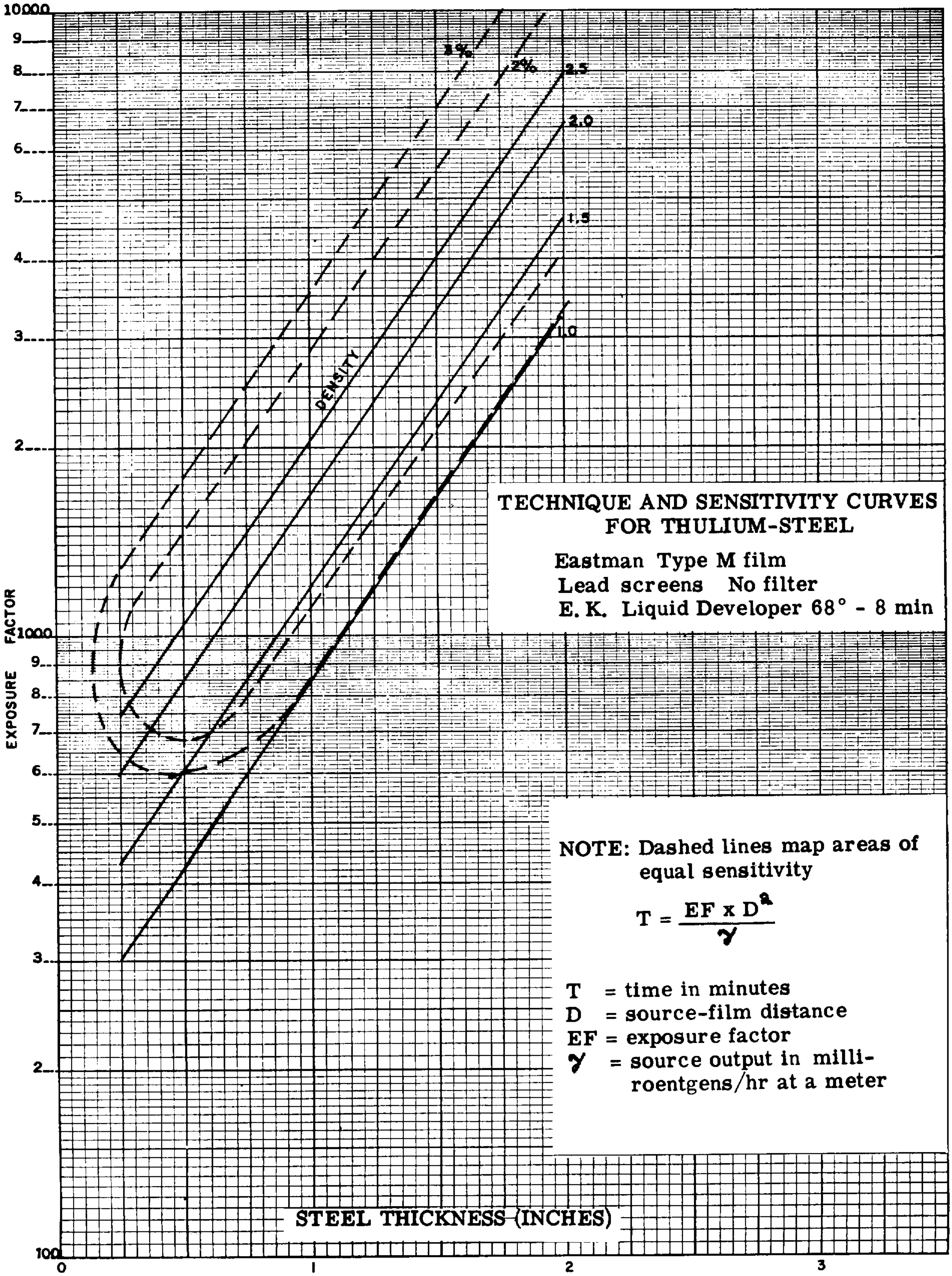

TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type M film
Lead screens No filter
E. K. Liquid Developer 68° - 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
DENSITY
2%
2.5
2.0
1.5
1.0
10000
1000
100
0
1
2
3

Chart No. 1

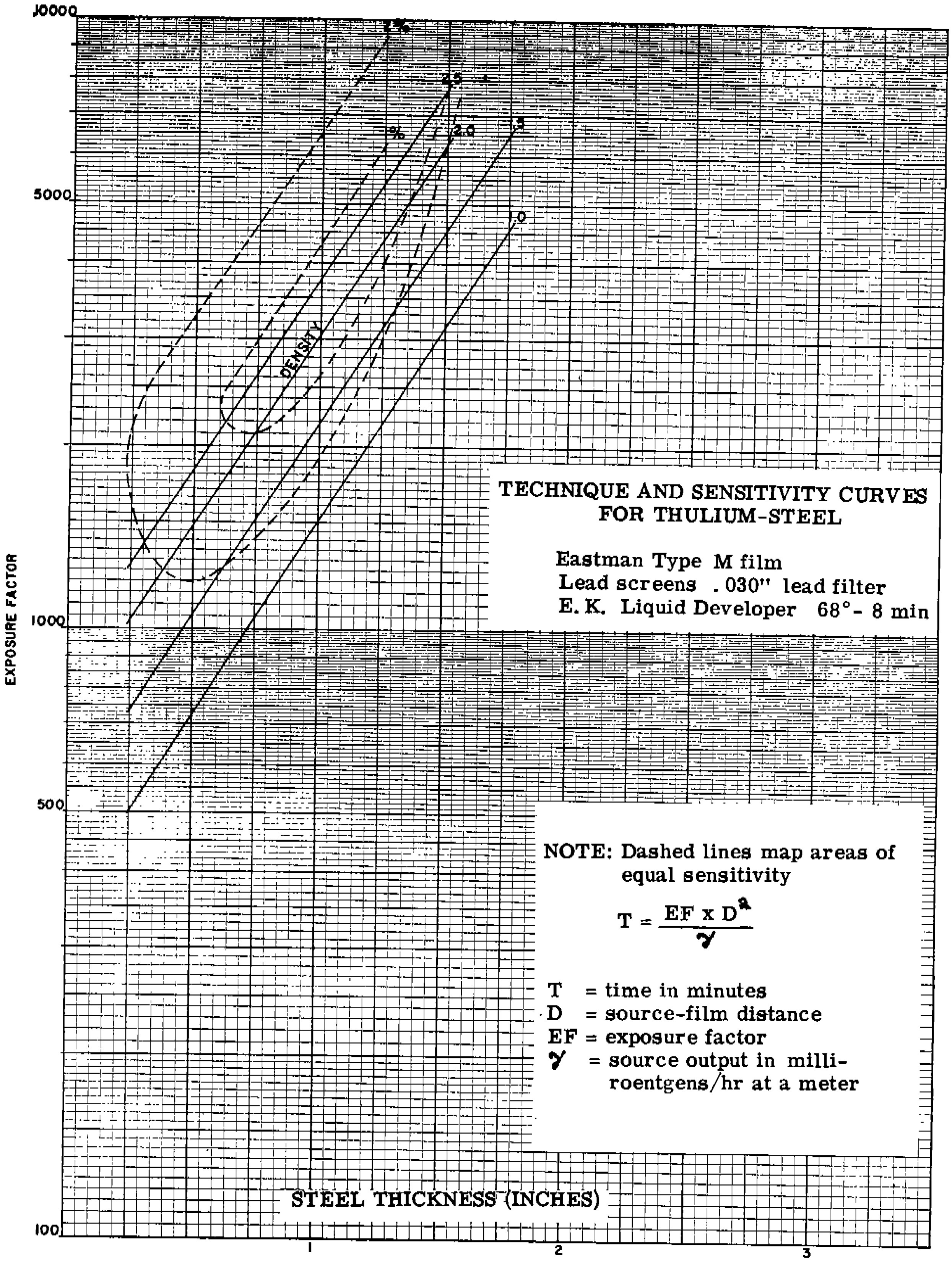

10000
5000
1000
500
100
EXPOSURE FACTOR
2%
1%
2.5
2.0
1.5
1.0
DENSITY
TECHNIQUE AND SENSITIVITY CURVES
FOR THULIUM-STEEL
Eastman Type M film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
STEEL THICKNESS (INCHES)
1
2
3

Chart No. 2

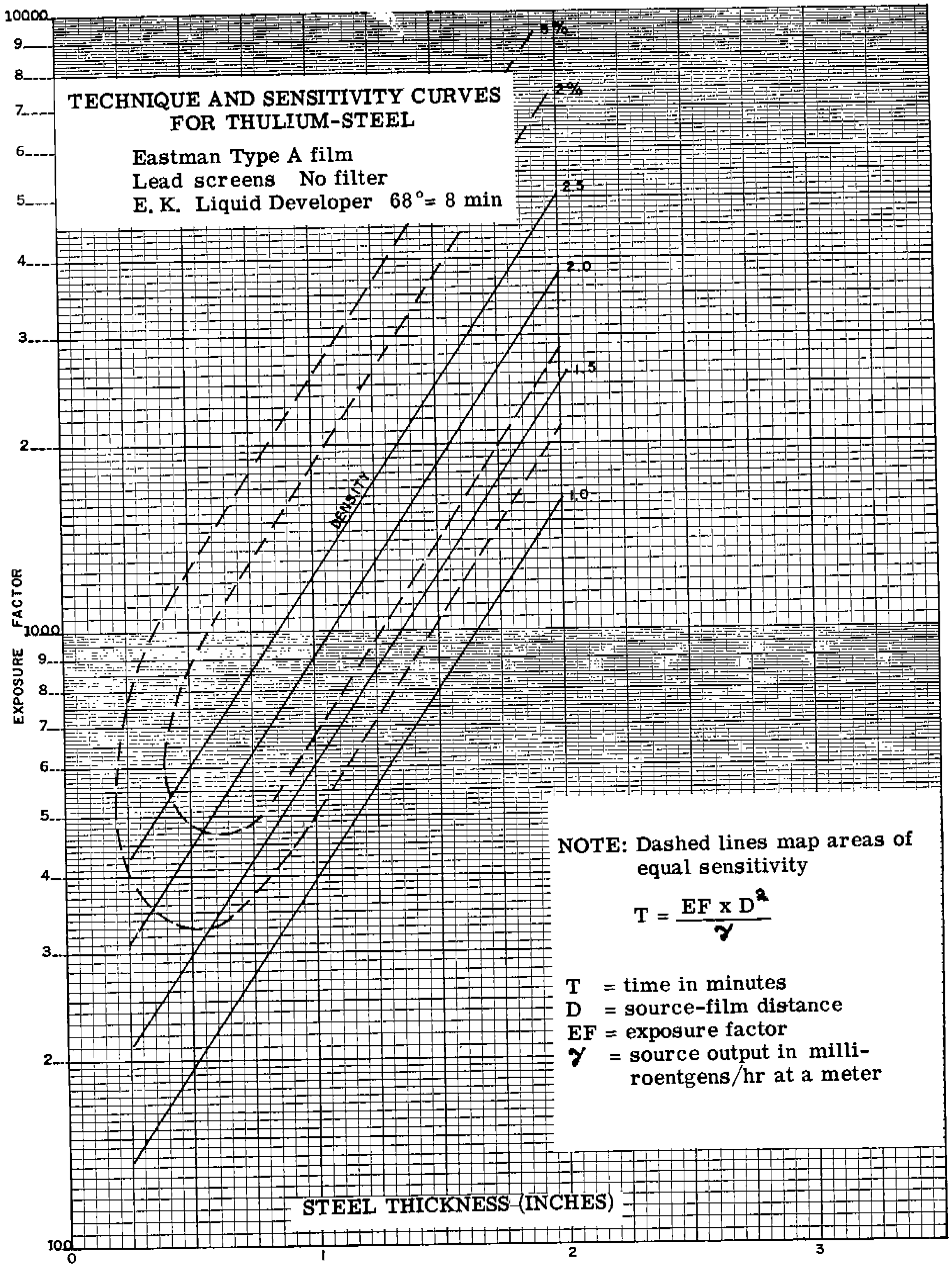

TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type A film
Lead screens No filter
E. K. Liquid Developer 68°= 8 min
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
DENSITY
3%
2%
2.5
2.0
1.5
1.0
10000
9
8
7
6
5
4
3
2
1000
100
0
1
2
3

Chart No. 3

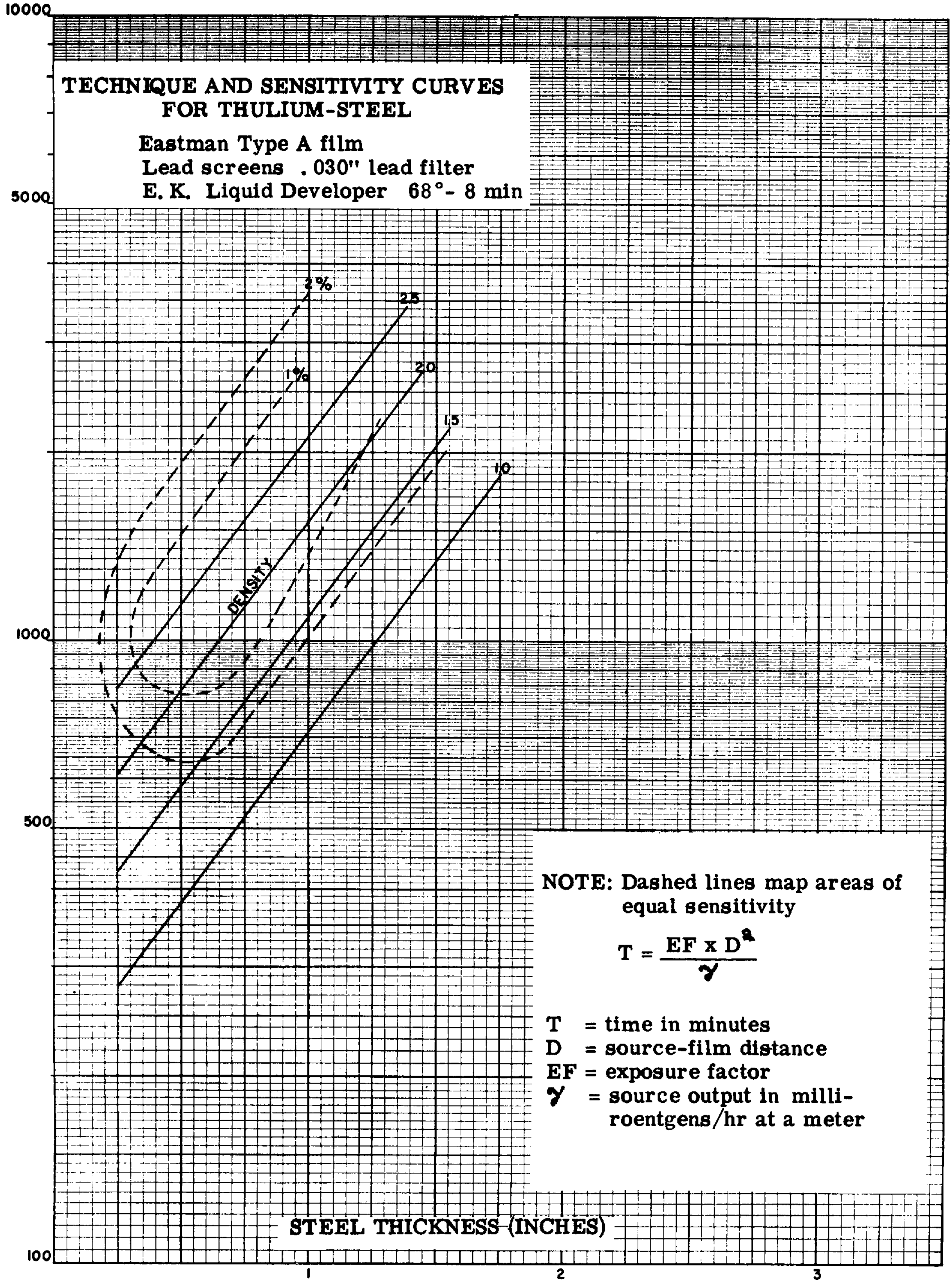

TECHNIQUE AND SENSITIVITY CURVES
FOR THULIUM-STEEL
Eastman Type A film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
10000
5000
1000
500
100
EXPOSURE FACTOR
2%
1%
2.5
2.0
1.5
1.0
DENSITY
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
STEEL THICKNESS (INCHES)
1
2
3

Chart No. 4

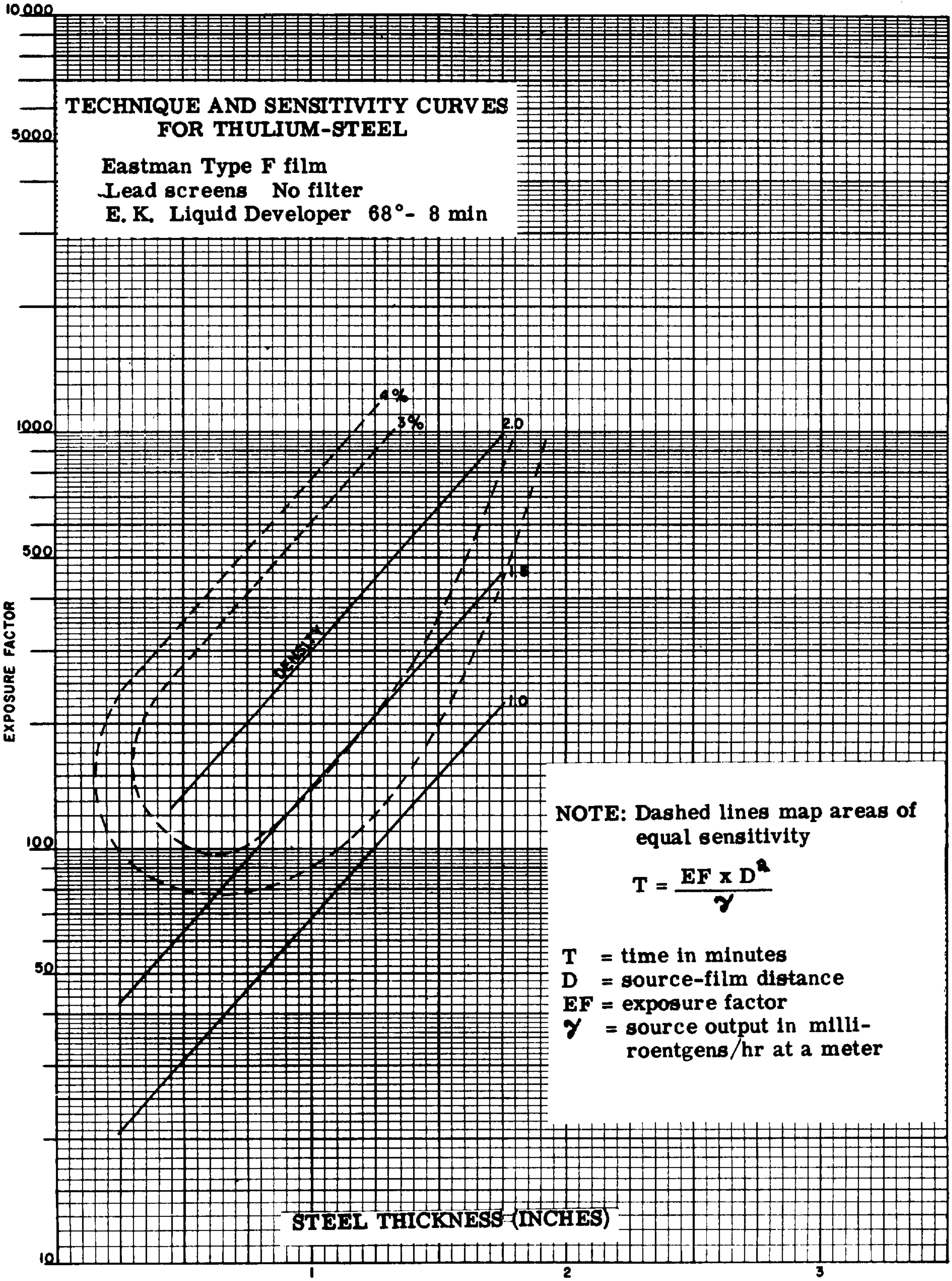

TECHNIQUE AND SENSITIVITY CURVES
FOR THULIUM-STEEL
Eastman Type F film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
4%
3%
2.0
1.5
1.0
DENSITY
10,000
5000
1000
500
100
50
10
EXPOSURE FACTOR
1
2
3
STEEL THICKNESS (INCHES)

Chart No. 5

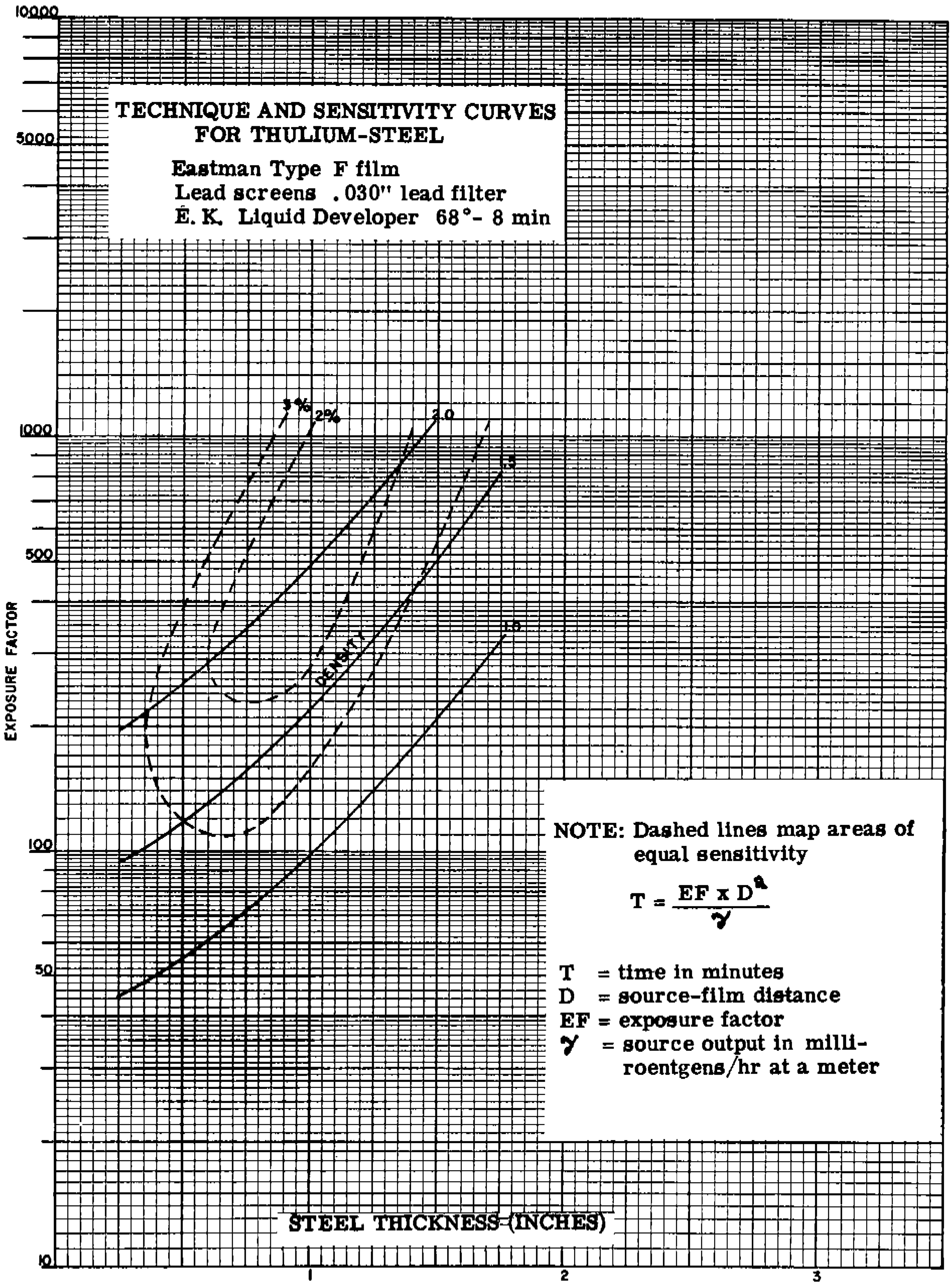

TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type F film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
10000
5000
1000
500
100
50
10
1
2
3
3%
2%
2.0
1.5
1.0
DENSITY

Chart No. 6

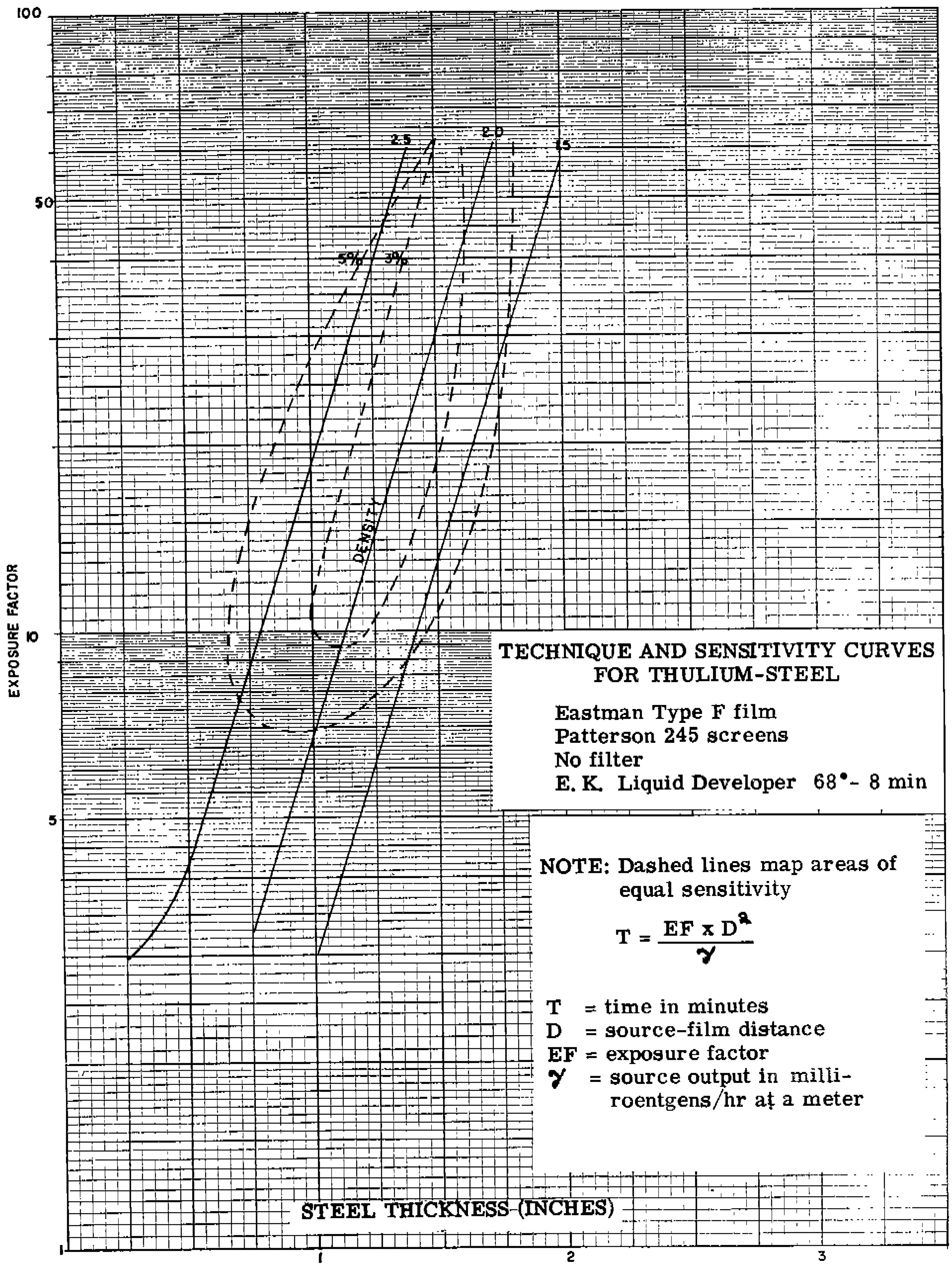

100
50
10
5
1
2.5
2.0
1.5
5%
3%
DENSITY
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
1
2
3
TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type F film
Patterson 245 screens
No filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 7

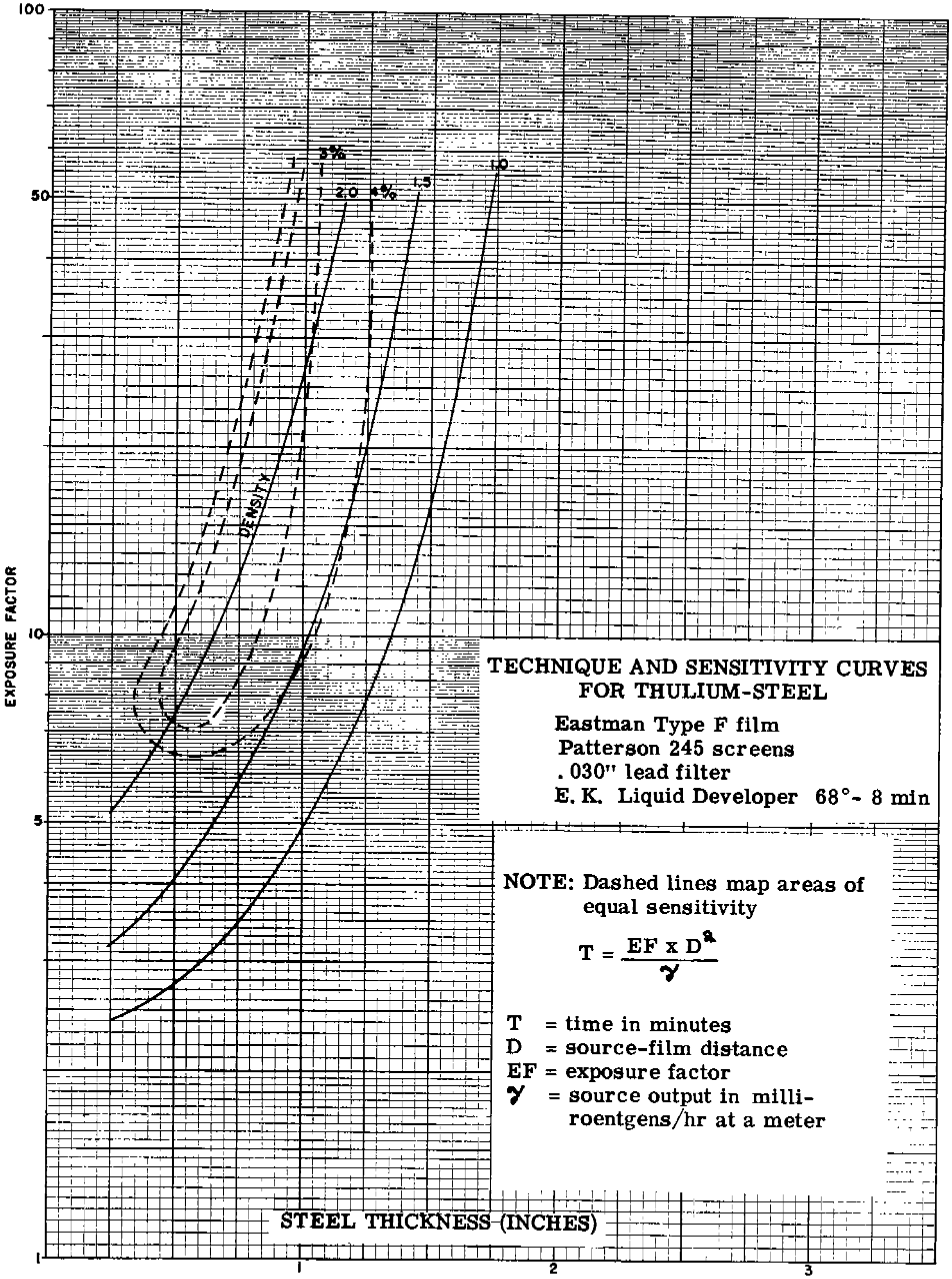
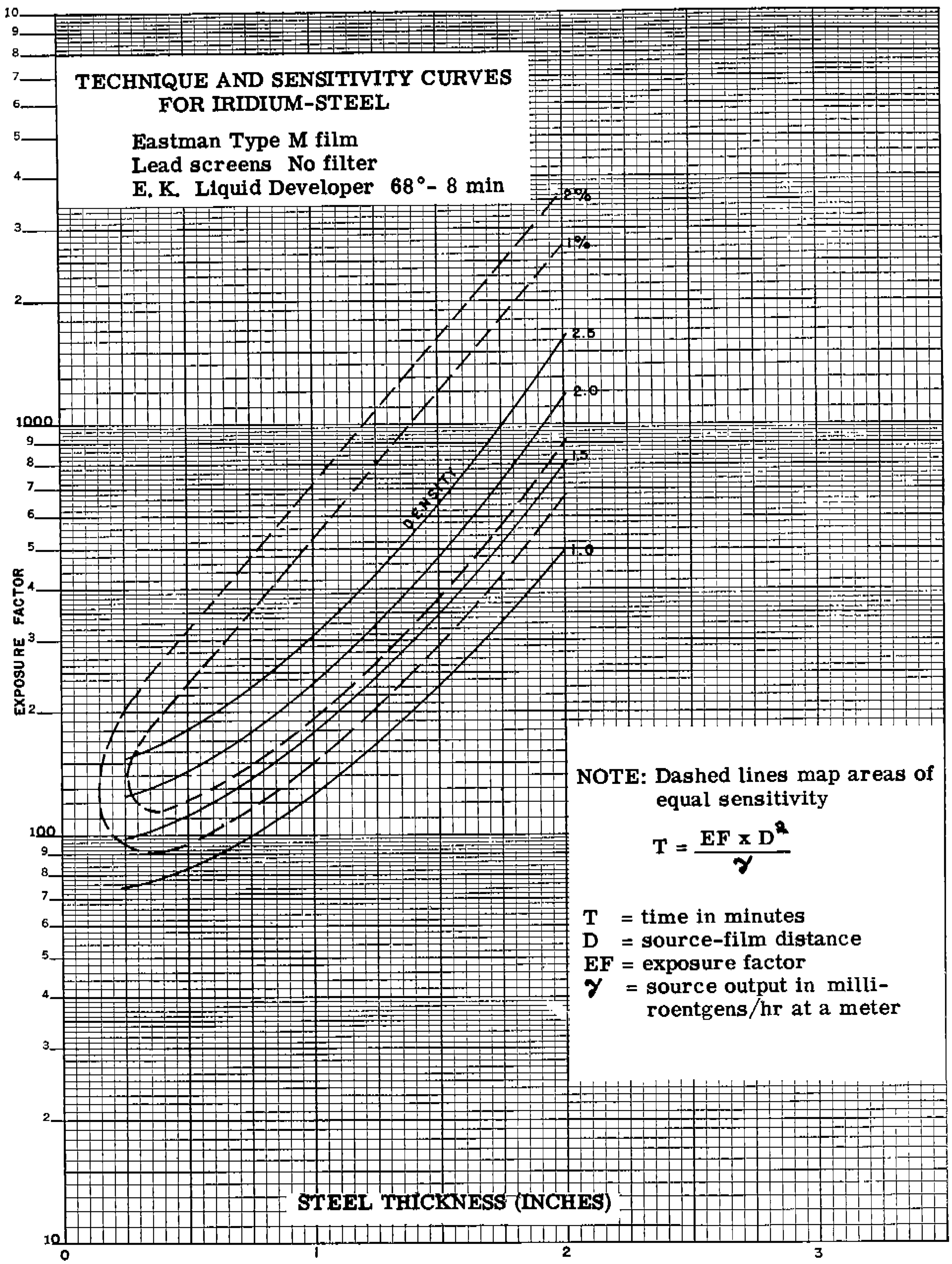

100
50
10
5
1
EXPOSURE FACTOR
1
2
3
STEEL THICKNESS (INCHES)
3%
4%
2.0
1.5
1.0
DENSITY
TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type F film
Patterson 245 screens
.030" lead filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 8



TECHNIQUE AND SENSITIVITY CURVES FOR IRIDIUM-STEEL
Eastman Type M film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
DENSITY
2%
1%
2.5
2.0
1.5
1.0
10
1000
100
0
1
2
3

Chart No. 9

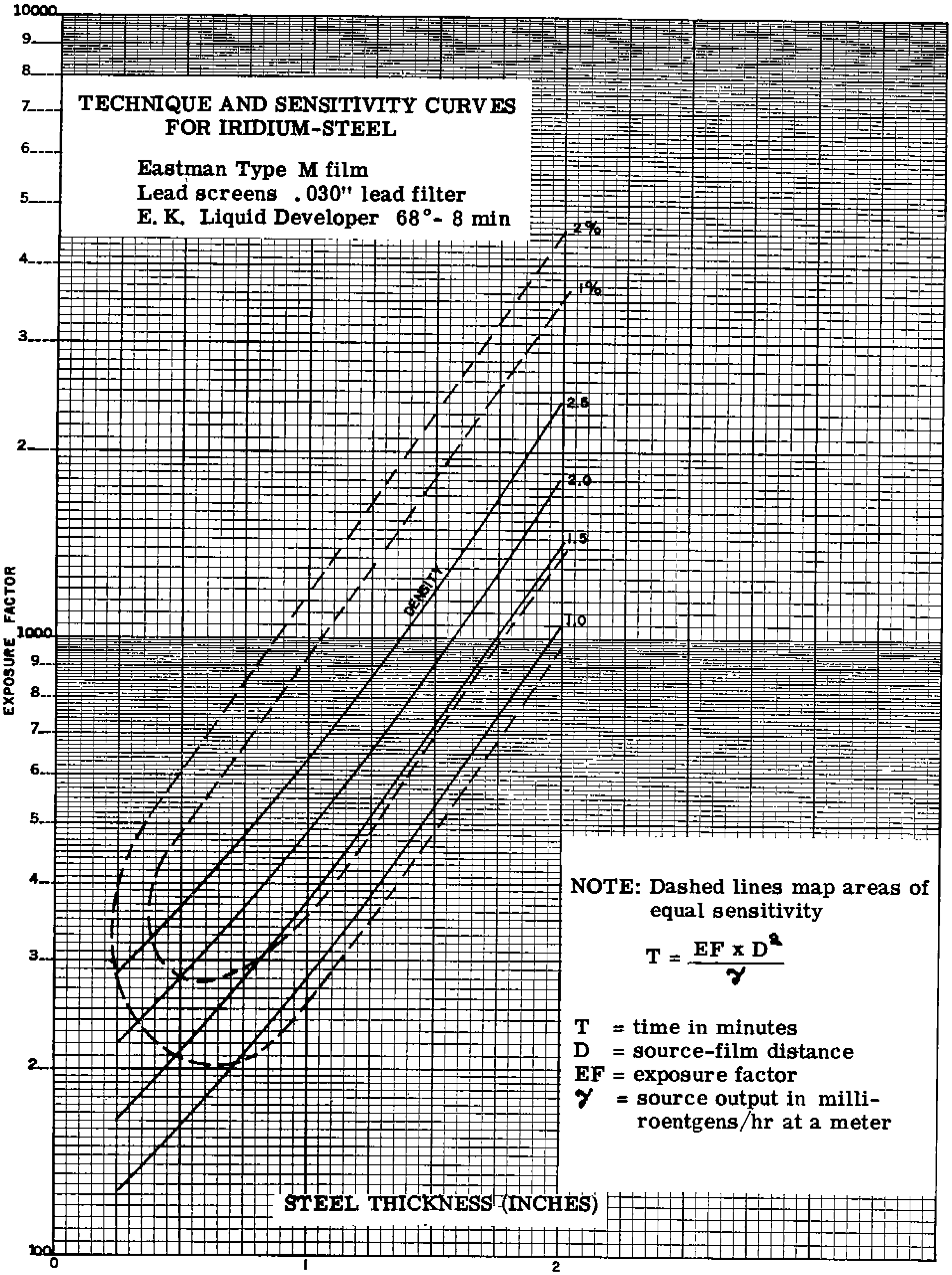

TECHNIQUE AND SENSITIVITY CURVES FOR IRIDIUM-STEEL
Eastman Type M film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
DENSITY
2%
1%
2.5
2.0
1.5
1.0
10000
1000
100
0
1
2
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 10

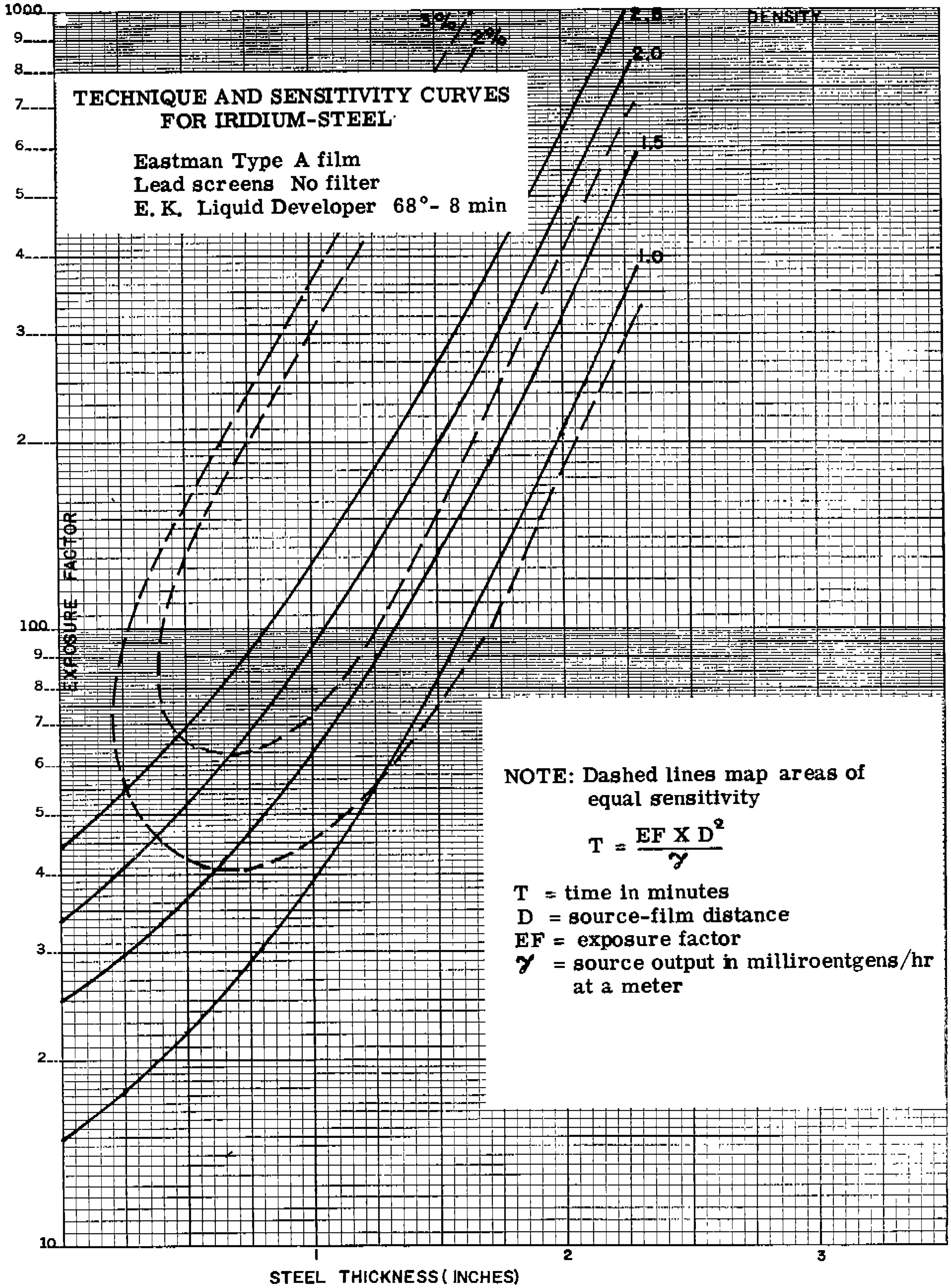
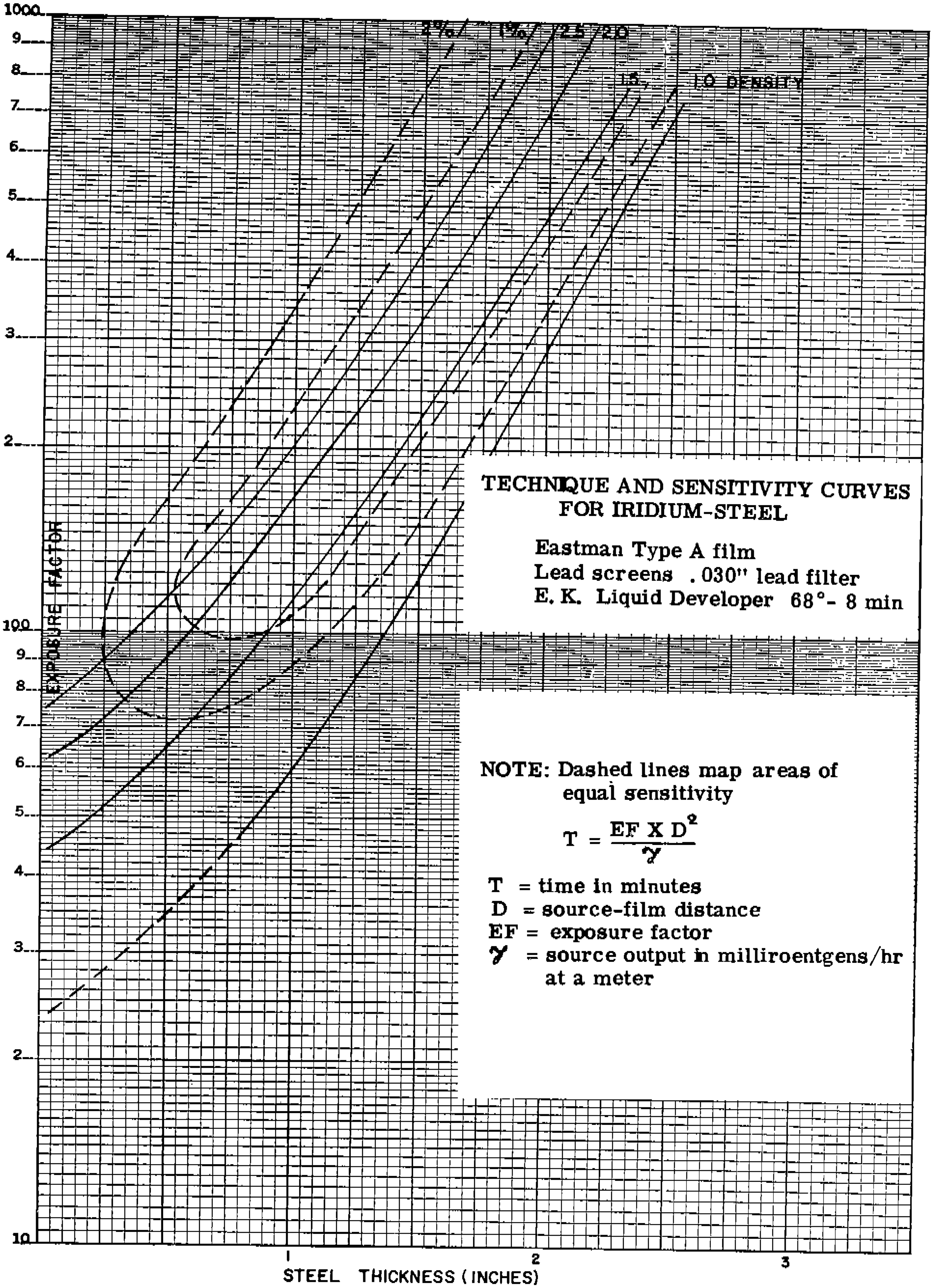

TECHNIQUE AND SENSITIVITY CURVES
FOR IRIDIUM-STEEL
Eastman Type A film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
3%
2%
2.5
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
1000
100
10
1
2
3
STEEL THICKNESS (INCHES)
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 11



1000
9
8
7
6
5
4
3
2
100
10
EXPOSURE FACTOR
2%
1%
2.5
2.0
1.5
1.0 DENSITY
1
2
3
STEEL THICKNESS (INCHES)
TECHNIQUE AND SENSITIVITY CURVES FOR IRIDIUM-STEEL
Eastman Type A film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 12

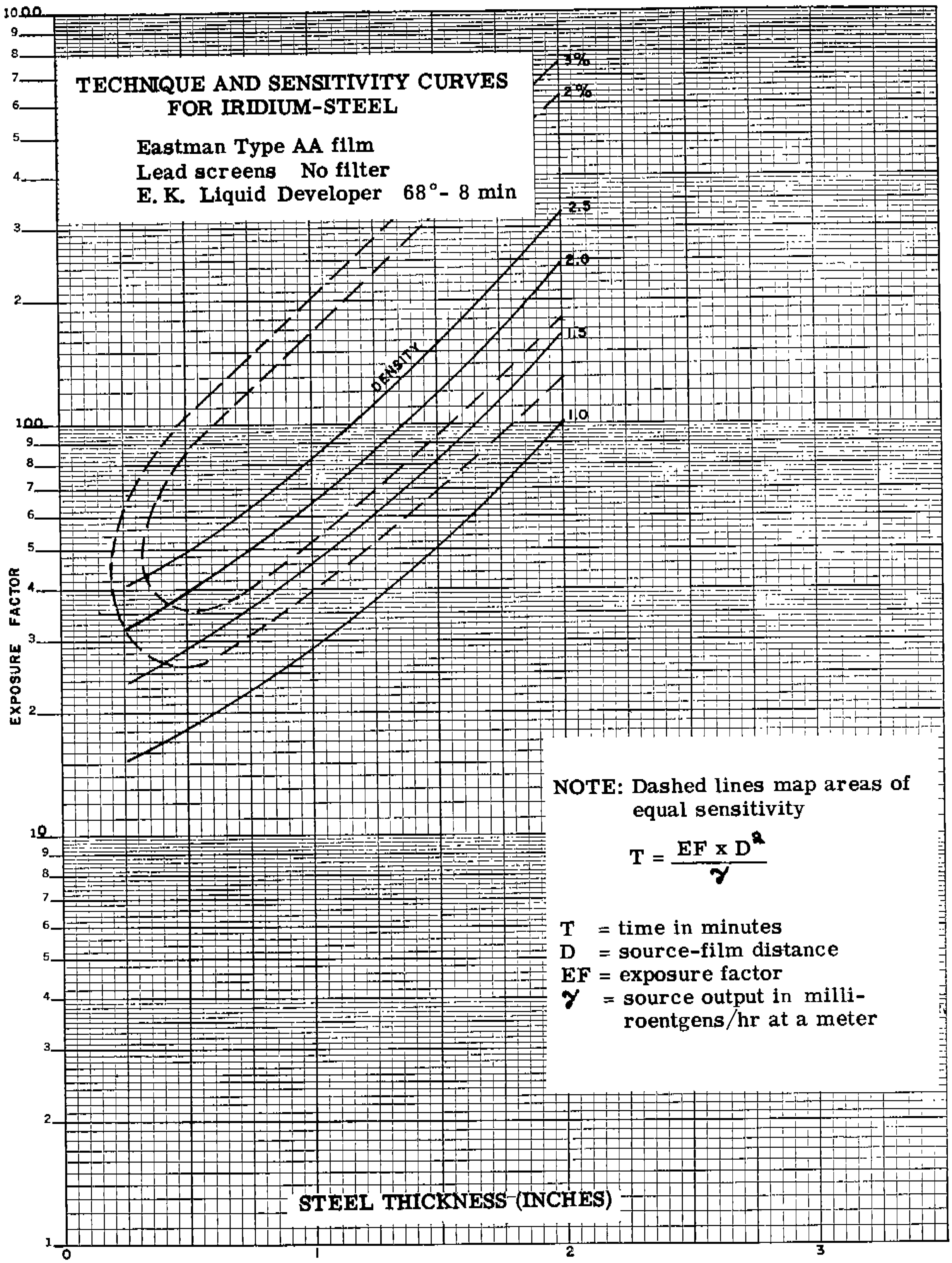

TECHNIQUE AND SENSITIVITY CURVES
FOR IRIDIUM-STEEL
Eastman Type AA film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
3%
2%
2.5
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
1000
100
10
1
STEEL THICKNESS (INCHES)
0
1
2
3
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 13

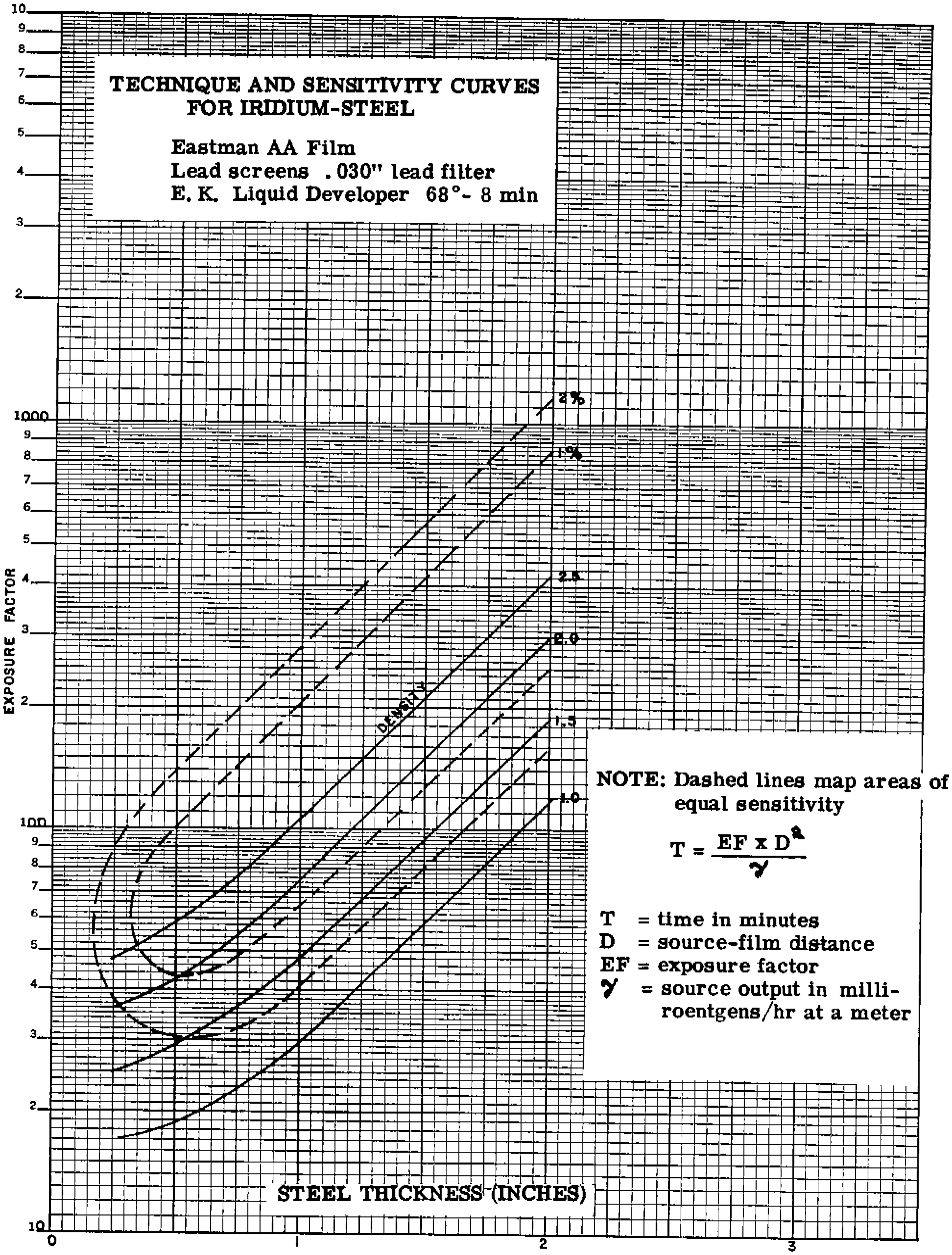

TECHNIQUE AND SENSITIVITY CURVES
FOR IRIDIUM-STEEL
Eastman AA Film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
DENSITY
2%
1%
2.5
2.0
1.5
1.0
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 14

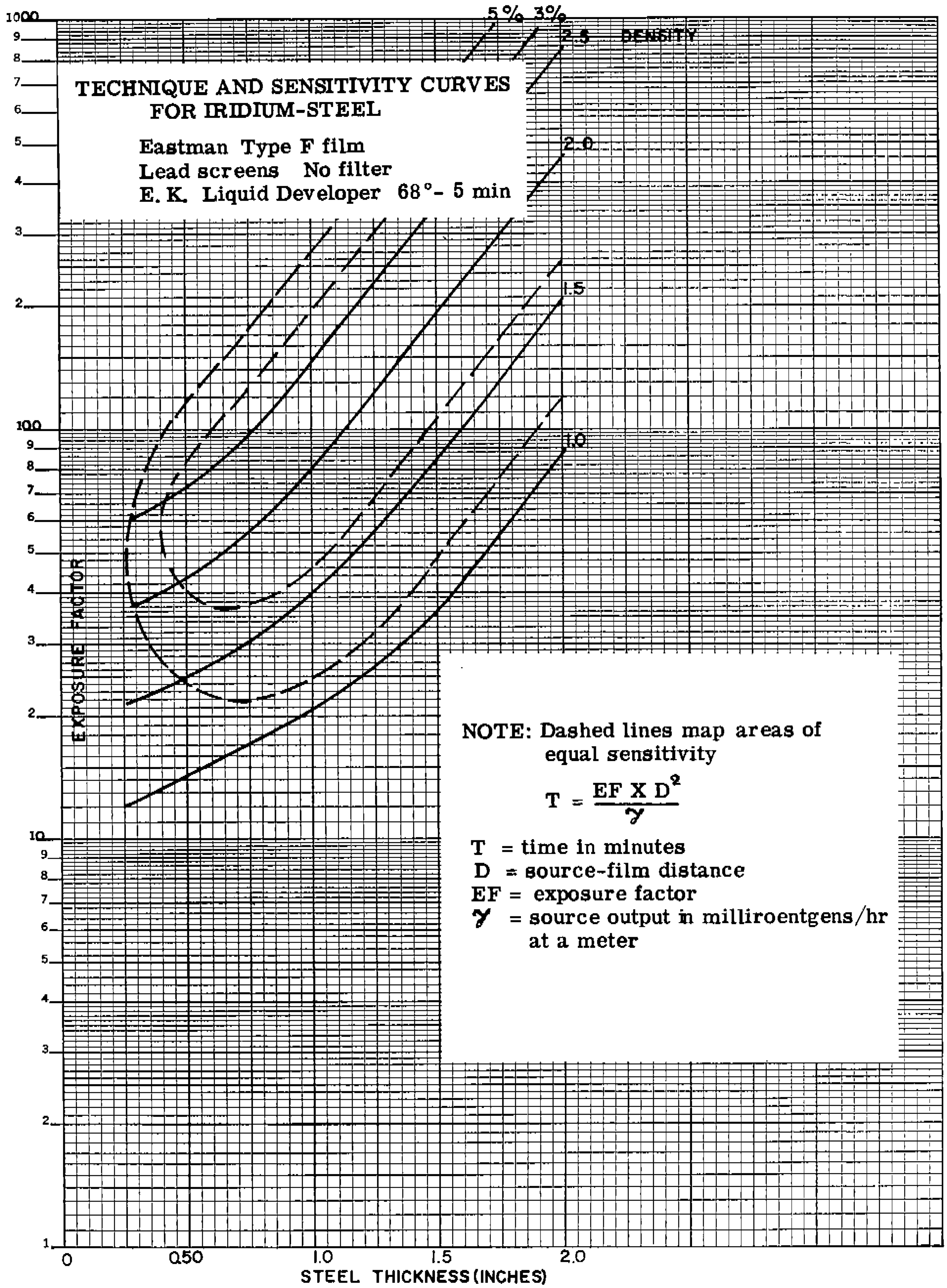
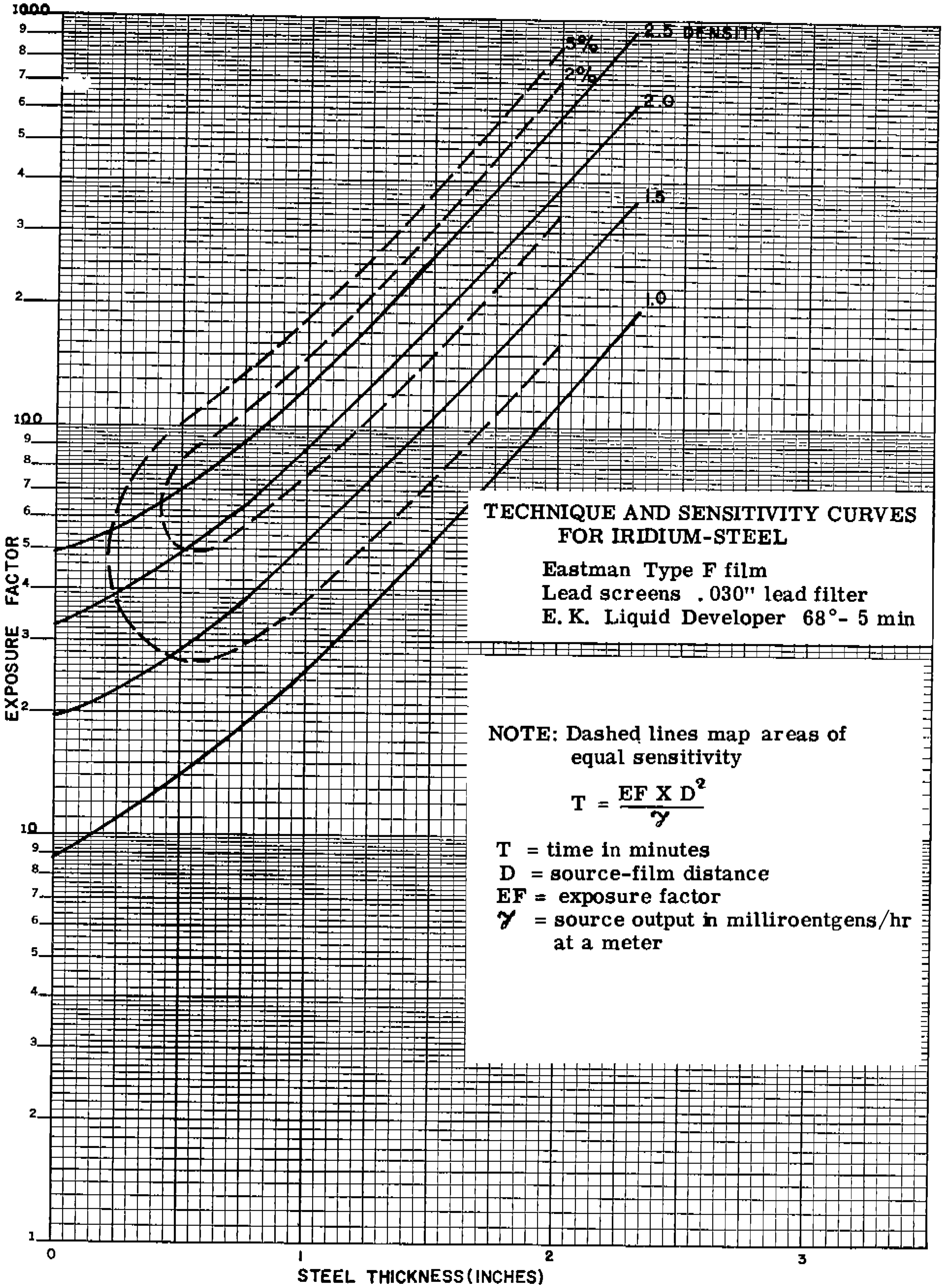

TECHNIQUE AND SENSITIVITY CURVES
FOR IRIDIUM-STEEL
Eastman Type F film
Lead screens No filter
E. K. Liquid Developer 68°- 5 min
5% 3%
2.5 DENSITY
2.0
1.5
1.0
NOTE: Dashed lines map areas of equal sensitivity
T = EF X D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter
EXPOSURE FACTOR
1000
100
10
1
0
0.50
1.0
1.5
2.0
STEEL THICKNESS (INCHES)

Chart No. 15



2.5 DENSITY
5%
2%
2.0
1.5
1.0
TECHNIQUE AND SENSITIVITY CURVES FOR IRIDIUM-STEEL
Eastman Type F film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 5 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter
EXPOSURE FACTOR
1000
100
10
1
0
1
2
3
STEEL THICKNESS (INCHES)

Chart No. 16

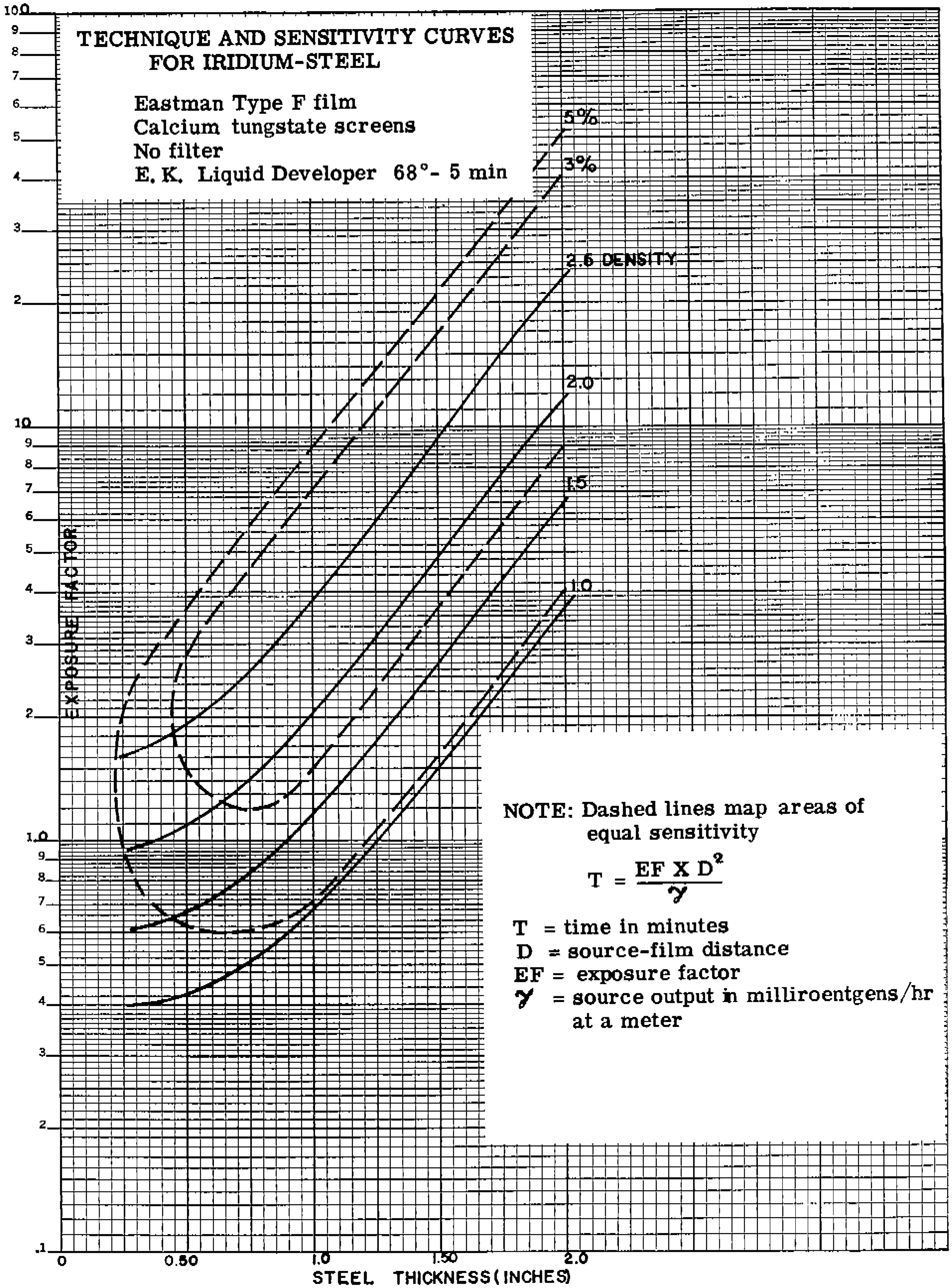

TECHNIQUE AND SENSITIVITY CURVES FOR IRIDIUM-STEEL
Eastman Type F film
Calcium tungstate screens
No filter
E. K. Liquid Developer 68°- 5 min
5%
3%
2.6 DENSITY
2.0
1.5
1.0
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
0
0.50
1.0
1.50
2.0
NOTE: Dashed lines map areas of equal sensitivity
T = EF X D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 17

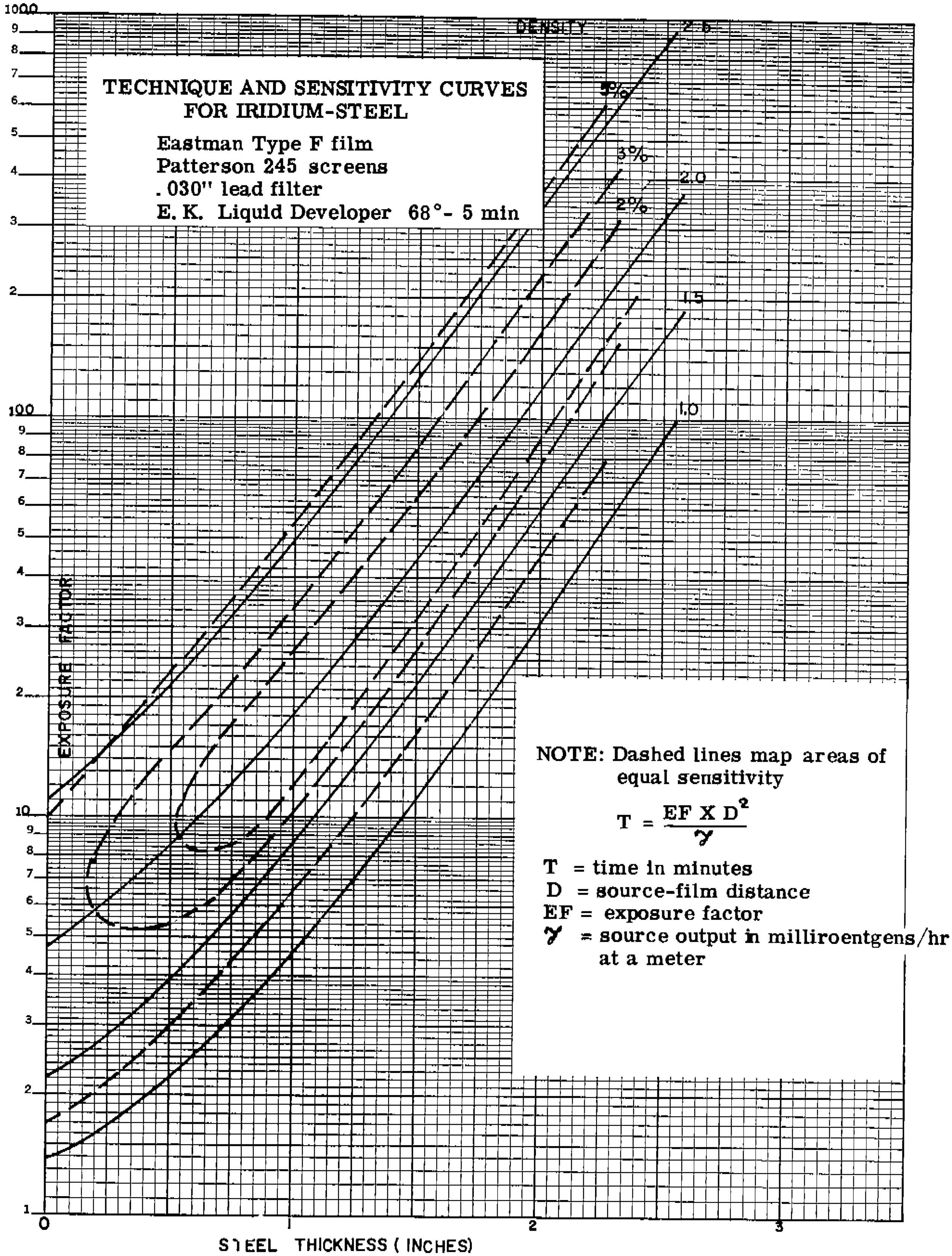

TECHNIQUE AND SENSITIVITY CURVES FOR IRIDIUM-STEEL
Eastman Type F film
Patterson 245 screens
.030" lead filter
E. K. Liquid Developer 68°- 5 min
DENSITY
2.5
5%
3%
2.0
2%
1.5
1.0
EXPOSURE FACTOR
NOTE: Dashed lines map areas of equal sensitivity
T = EF X D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter
1000
100
10
1
0
1
2
3
STEEL THICKNESS (INCHES)

Chart No. 18

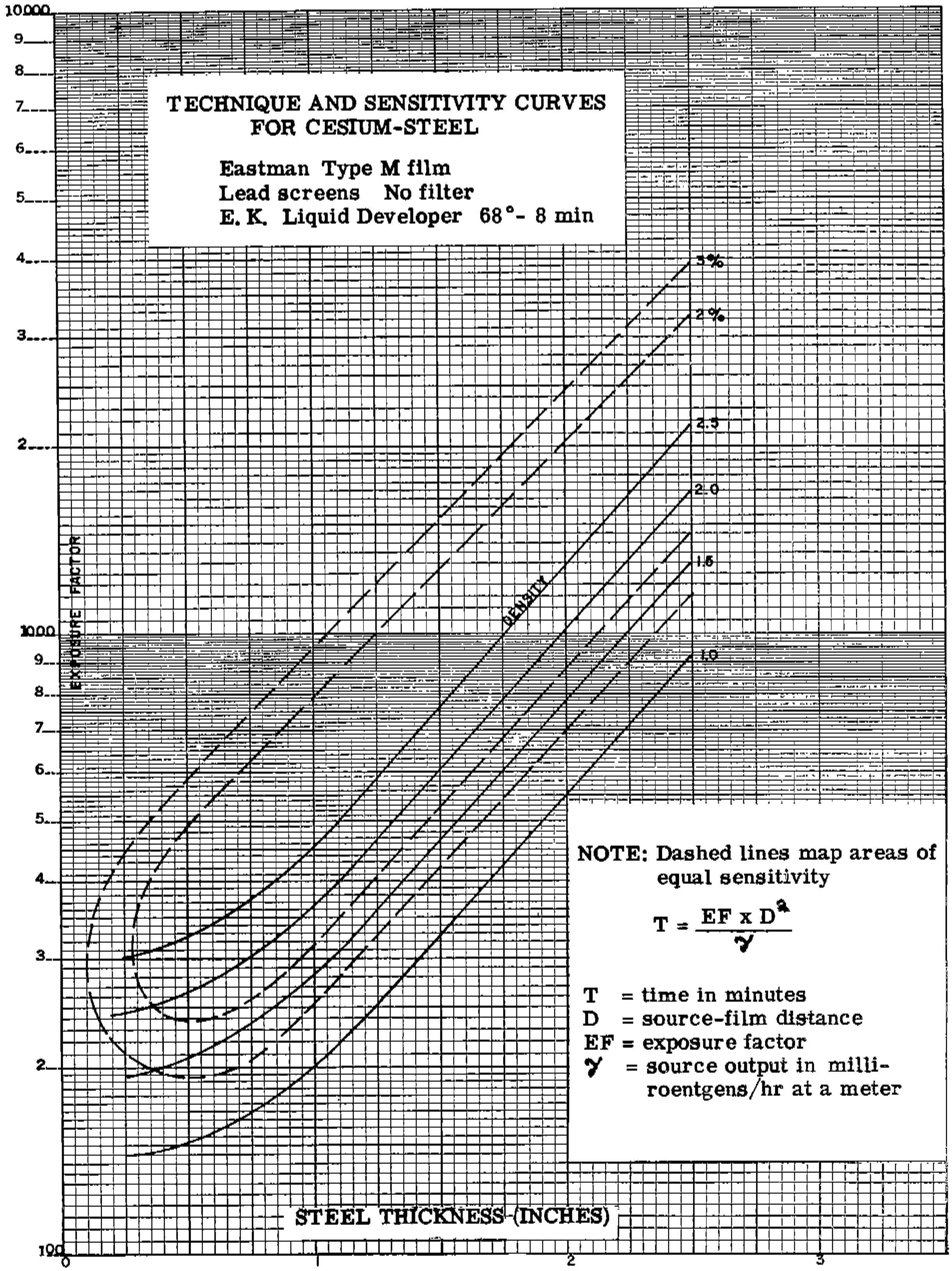

TECHNIQUE AND SENSITIVITY CURVES FOR CESIUM-STEEL
Eastman Type M film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
3%
2%
2.5
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
10000
9
8
7
6
5
4
3
2
1000
100
0
1
2
3
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
STEEL THICKNESS (INCHES)

Chart No. 19

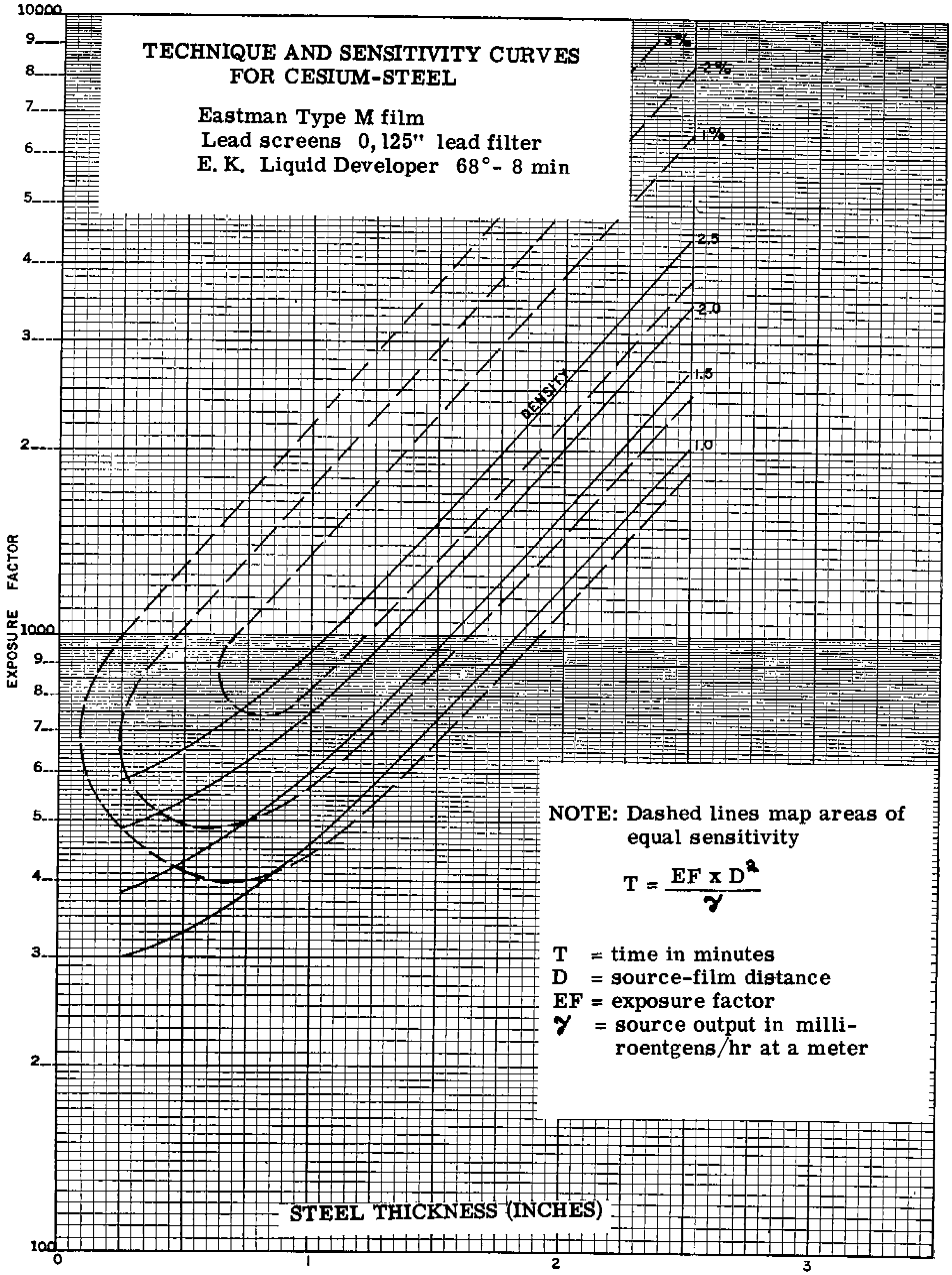

TECHNIQUE AND SENSITIVITY CURVES
FOR CESIUM-STEEL
Eastman Type M film
Lead screens 0,125" lead filter
E. K. Liquid Developer 68°- 8 min
3%
2%
1%
2.5
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
10000
1000
100
STEEL THICKNESS (INCHES)
0
1
2
3
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 20

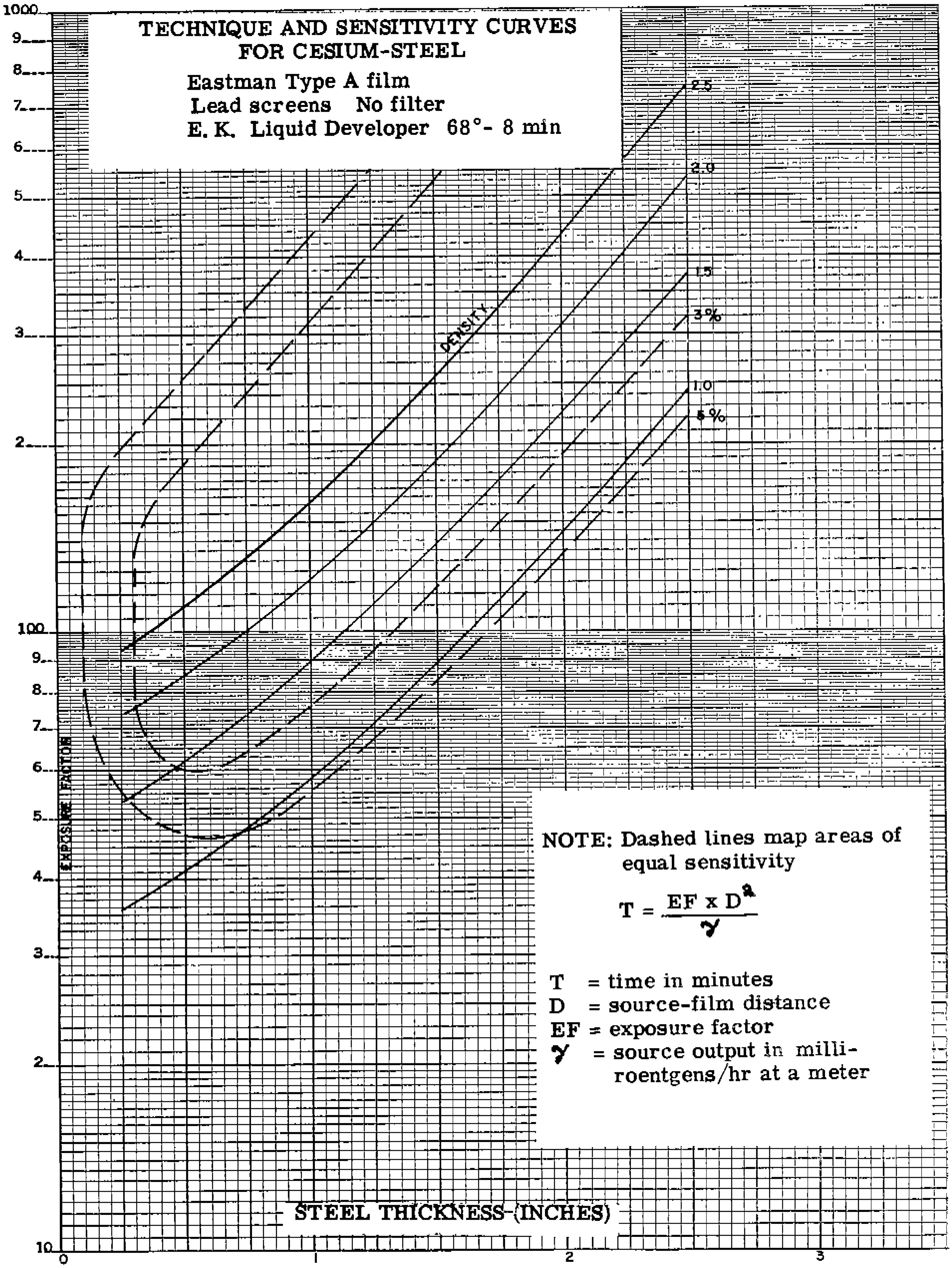

TECHNIQUE AND SENSITIVITY CURVES
FOR CESIUM-STEEL
Eastman Type A film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
DENSITY
2.5
2.0
1.5
3%
1.0
5%
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D2 / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 21

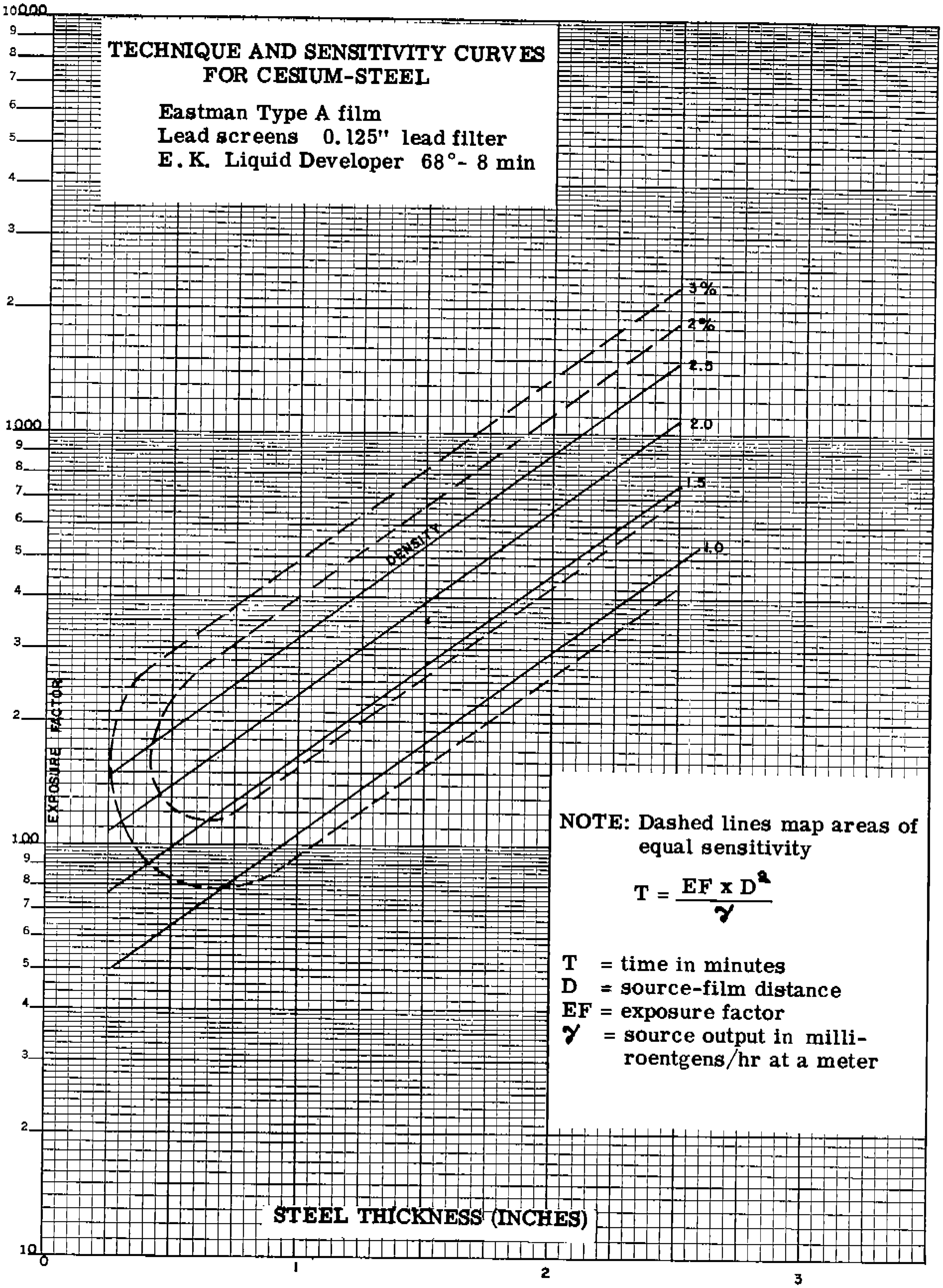

TECHNIQUE AND SENSITIVITY CURVES FOR CESIUM-STEEL
Eastman Type A film
Lead screens 0.125" lead filter
E.K. Liquid Developer 68°- 8 min
3%
2%
2.5
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
STEEL THICKNESS (INCHES)
10,000
1,000
100
10
0
1
2
3

Chart No. 22

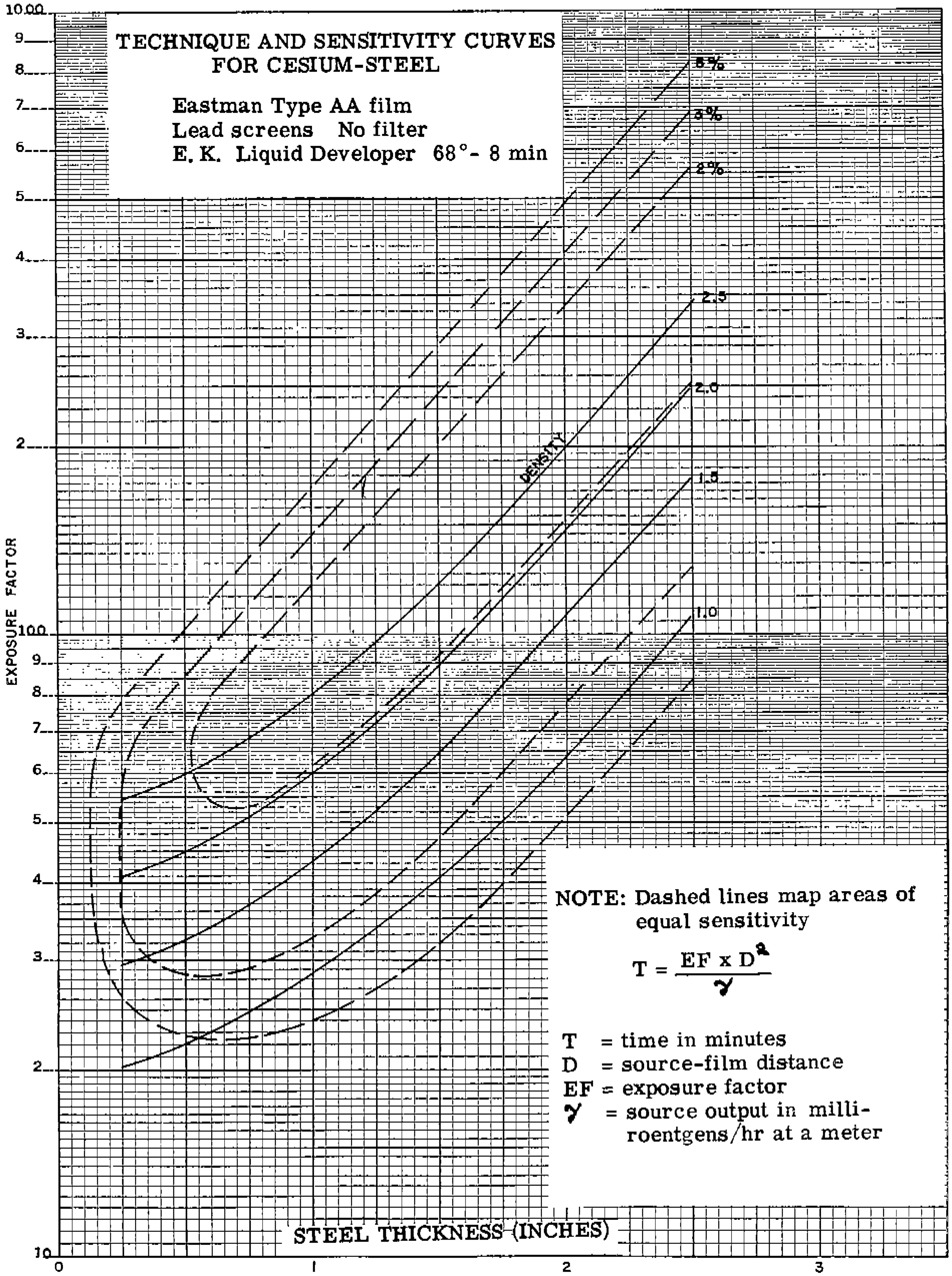
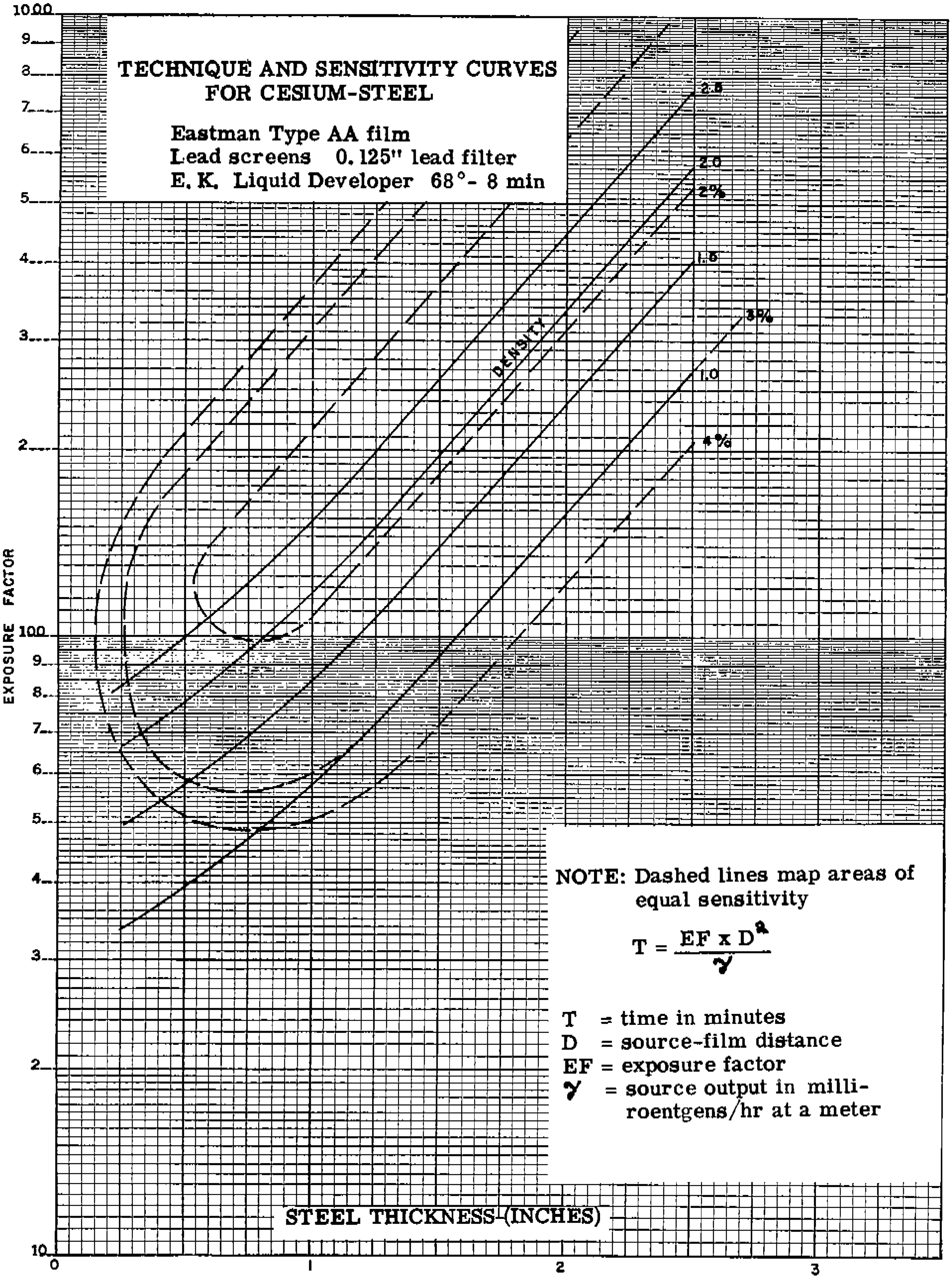
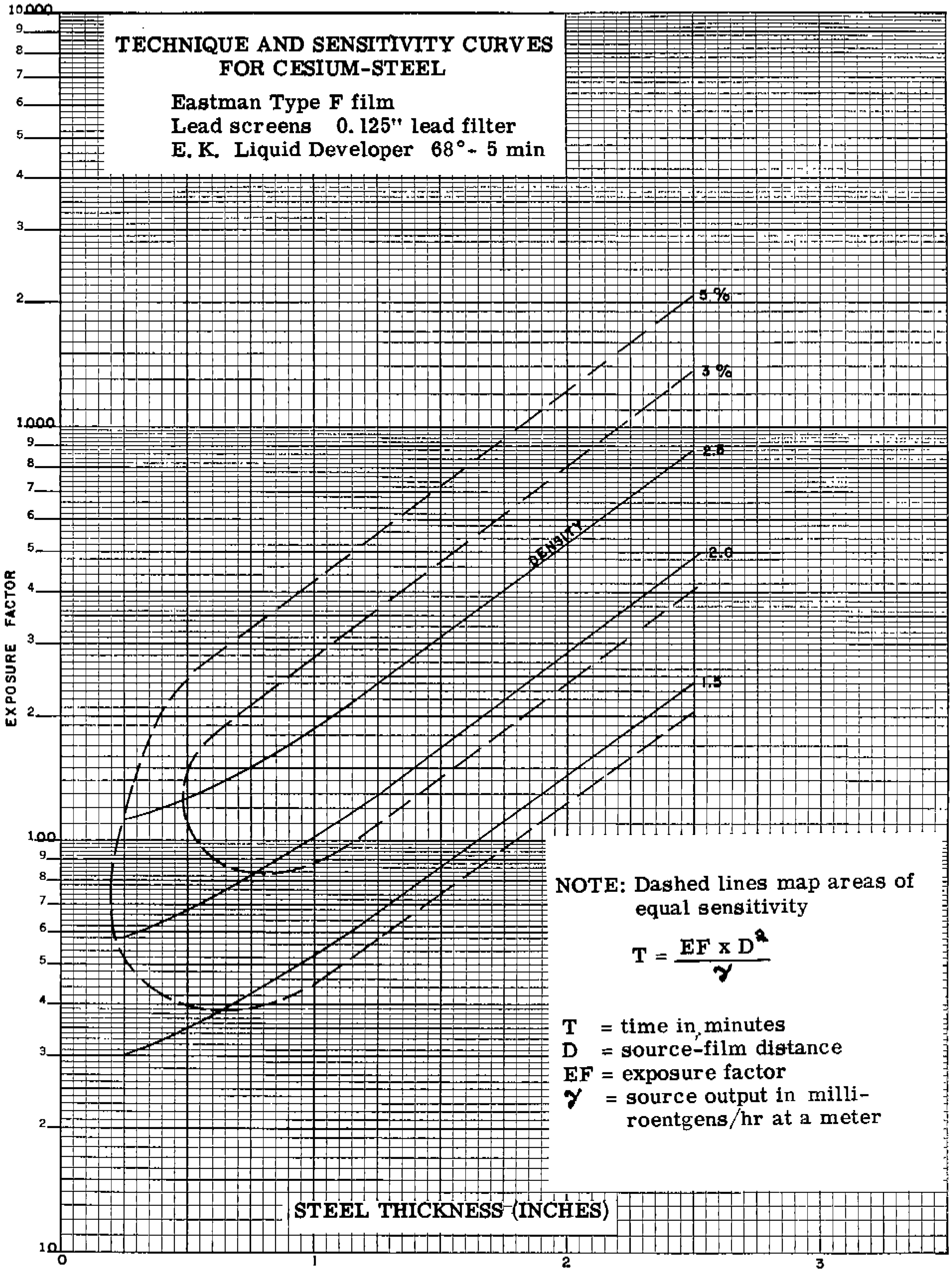

TECHNIQUE AND SENSITIVITY CURVES
FOR CESIUM-STEEL
Eastman Type AA film
Lead screens No filter
E. K. Liquid Developer 68° - 8 min
8%
3%
2%
2.5
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
1000
100
10
STEEL THICKNESS (INCHES)
0
1
2
3
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 23



TECHNIQUE AND SENSITIVITY CURVES FOR CESIUM-STEEL
Eastman Type AA film
Lead screens 0.125" lead filter
E.K. Liquid Developer 68°- 8 min
DENSITY
2.5
2.0
2%
1.5
3%
1.0
4%
EXPOSURE FACTOR
1000
100
10
STEEL THICKNESS (INCHES)
0
1
2
3
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 24



TECHNIQUE AND SENSITIVITY CURVES
FOR CESIUM-STEEL
Eastman Type F film
Lead screens 0.125" lead filter
E.K. Liquid Developer 68° - 5 min
5 %
3 %
2.5
DENSITY
2.0
1.5
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
10,000
1,000
100
10
0
1
2
3

Chart No. 25

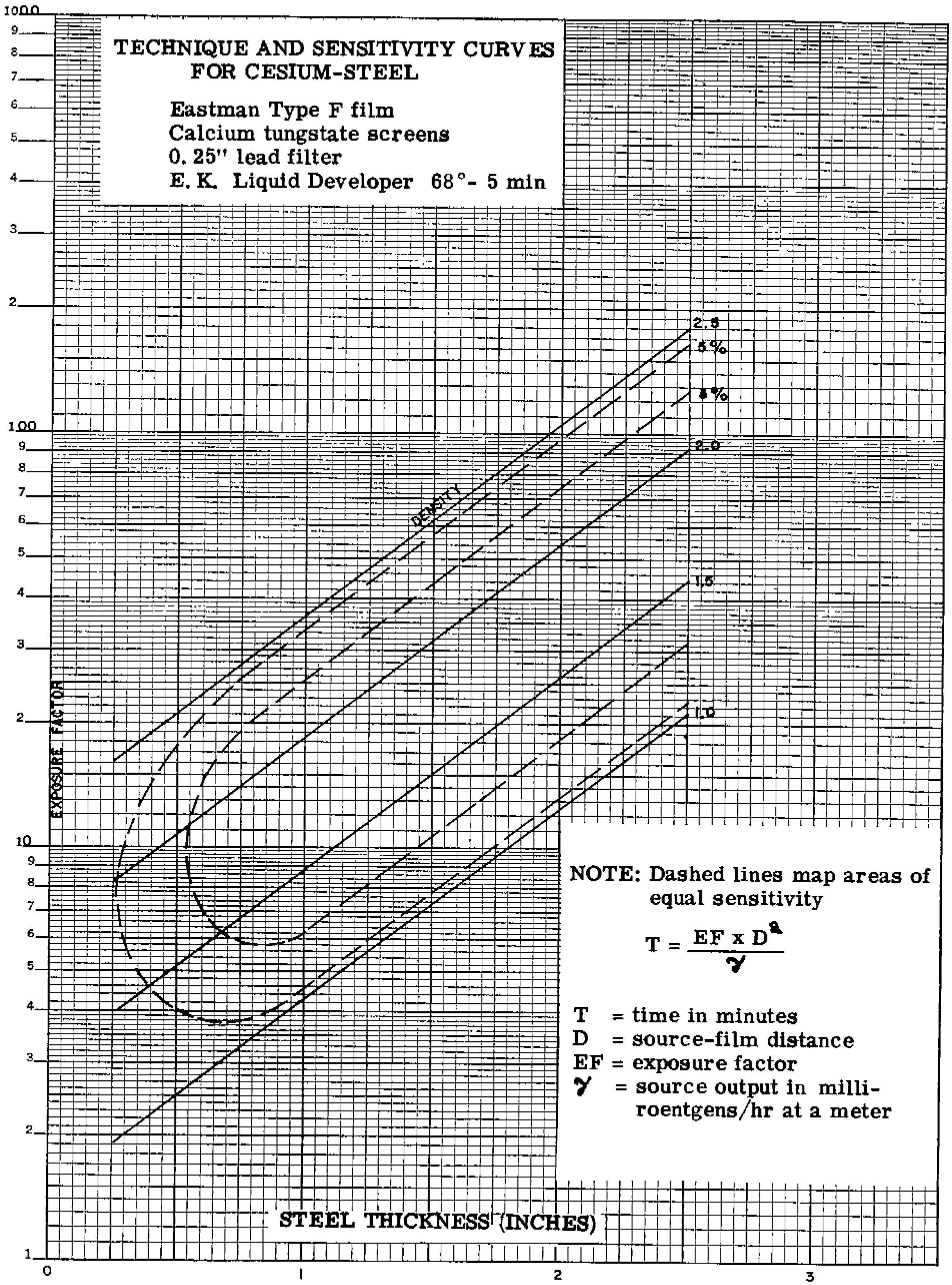

TECHNIQUE AND SENSITIVITY CURVES
FOR CESIUM-STEEL
Eastman Type F film
Calcium tungstate screens
0. 25" lead filter
E. K. Liquid Developer 68°- 5 min
DENSITY
2.5
5%
2.0
1.5
1.0
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
1000
100
10
1
0
1
2
3

Chart No. 26

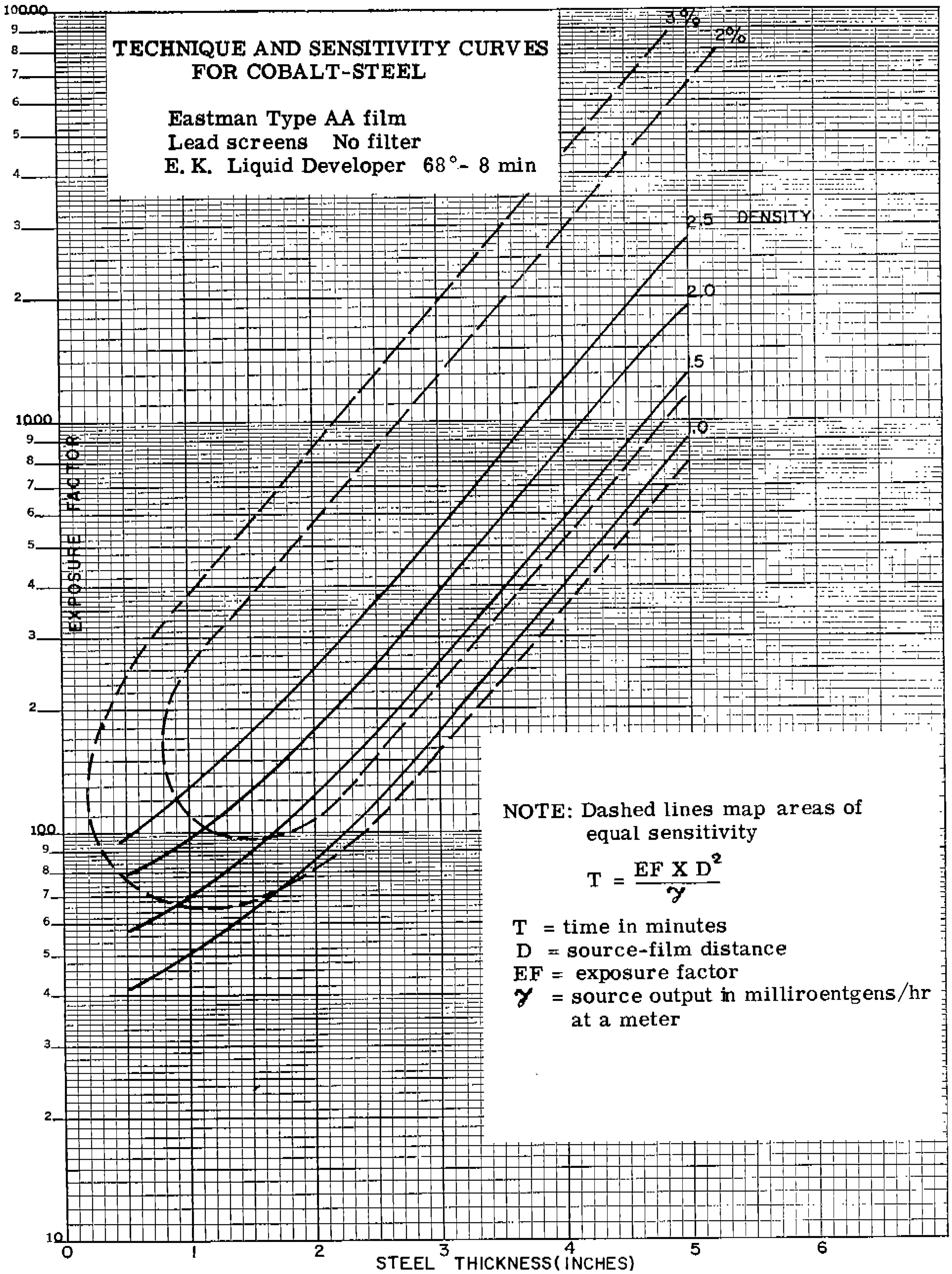

TECHNIQUE AND SENSITIVITY CURVES
FOR COBALT-STEEL
Eastman Type AA film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
3%
2%
2.5 DENSITY
2.0
1.5
1.0
EXPOSURE FACTOR
10000
1000
100
10
STEEL THICKNESS (INCHES)
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 27

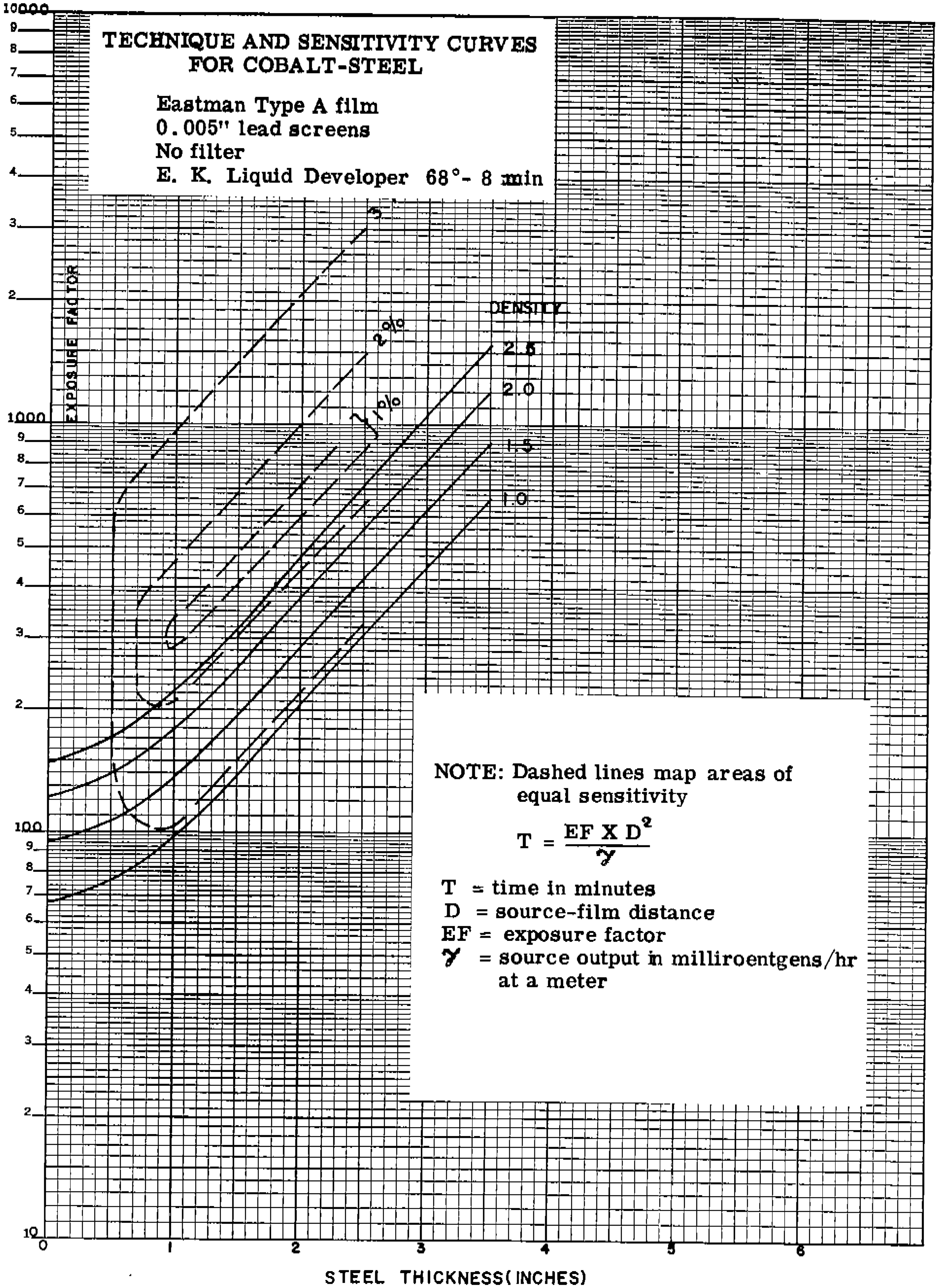
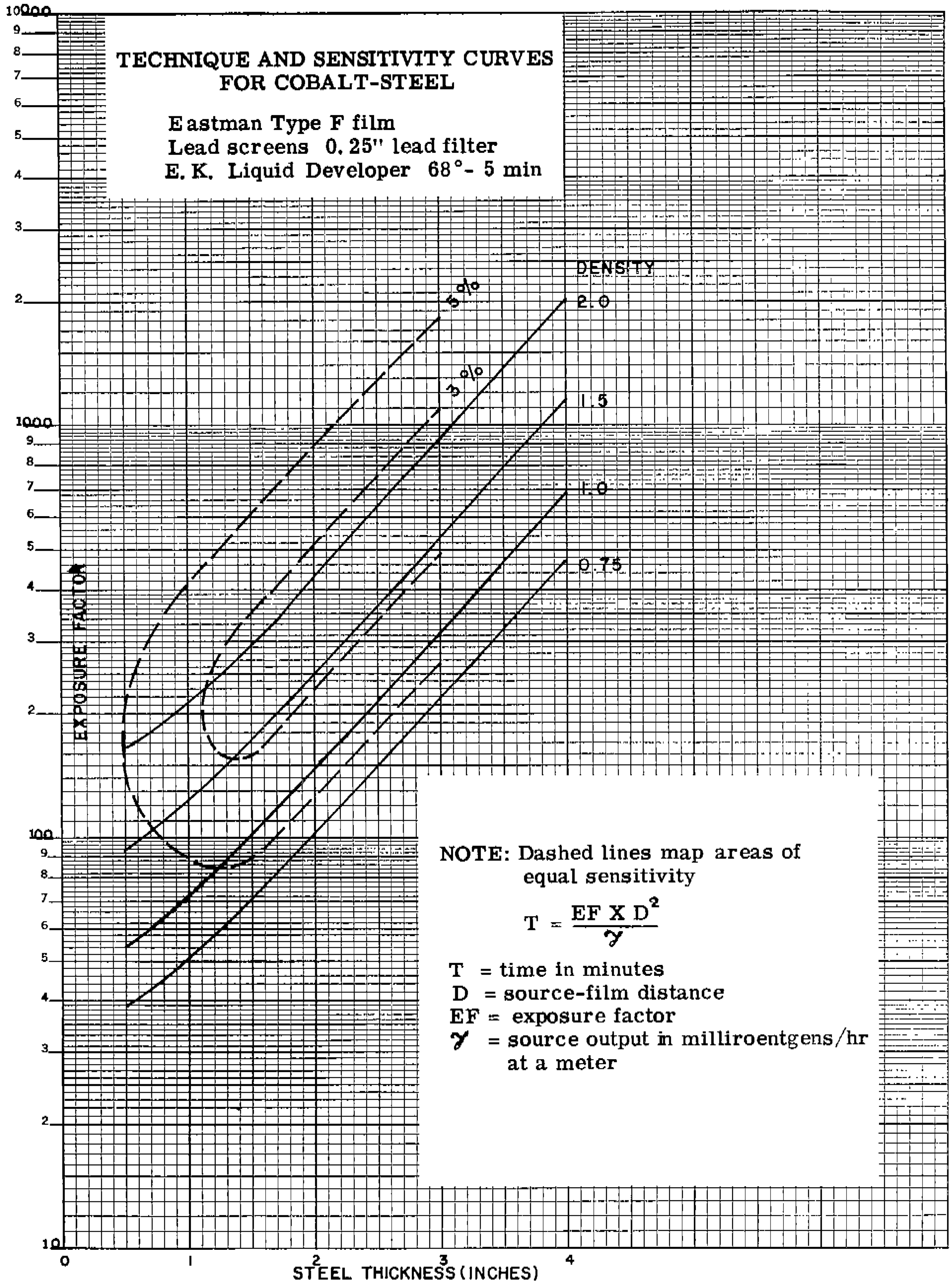

TECHNIQUE AND SENSITIVITY CURVES
FOR COBALT-STEEL
Eastman Type A film
0.005" lead screens
No filter
E. K. Liquid Developer 68°- 8 min
EXPOSURE FACTOR
DENSITY
2.5
2.0
1.5
1.0
3%
2%
1%
NOTE: Dashed lines map areas of equal sensitivity
T = EF X D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter
STEEL THICKNESS (INCHES)

Chart No. 28



TECHNIQUE AND SENSITIVITY CURVES FOR COBALT-STEEL
Eastman Type F film
Lead screens 0.25" lead filter
E. K. Liquid Developer 68°- 5 min
DENSITY
2.0
1.5
1.0
0.75
5%
3%
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
NOTE: Dashed lines map areas of equal sensitivity
T = EF X D²/γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 29

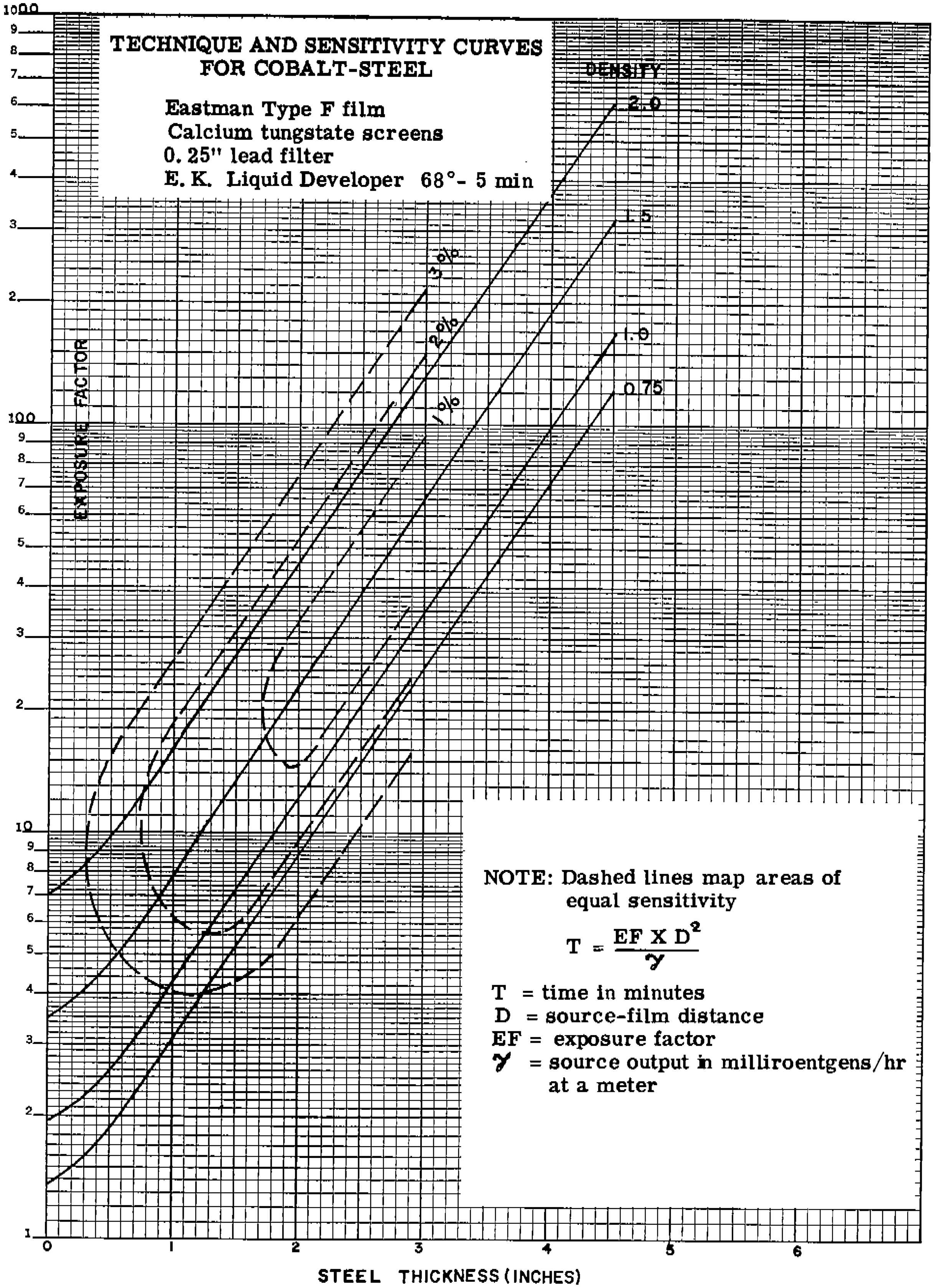
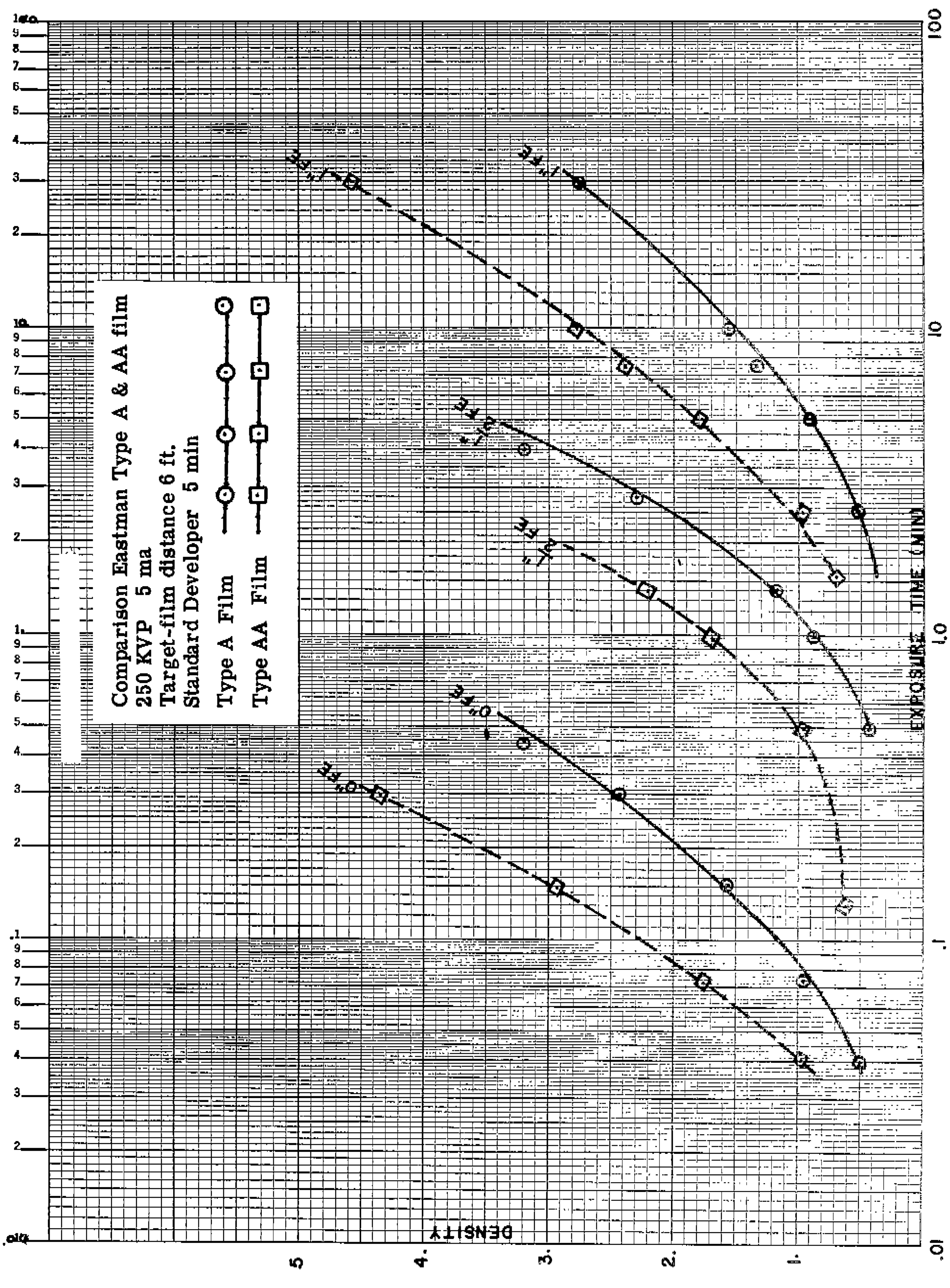

TECHNIQUE AND SENSITIVITY CURVES
FOR COBALT-STEEL
Eastman Type F film
Calcium tungstate screens
0.25" lead filter
E.K. Liquid Developer 68°- 5 min
DENSITY
2.0
1.5
1.0
0.75
3%
2%
1%
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
NOTE: Dashed lines map areas of equal sensitivity
T = EF X D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 30



Comparison Eastman Type A & AA film
250 KVP 5 ma
Target-film distance 6 ft.
Standard Developer 5 min
Type A Film
Type AA Film
EXPOSURE TIME (MIN)
DENSITY
100
10
1.0
.1
.01
5
4.
3.
2.
1.
1" Fe
0" Fe

Chart No. 31

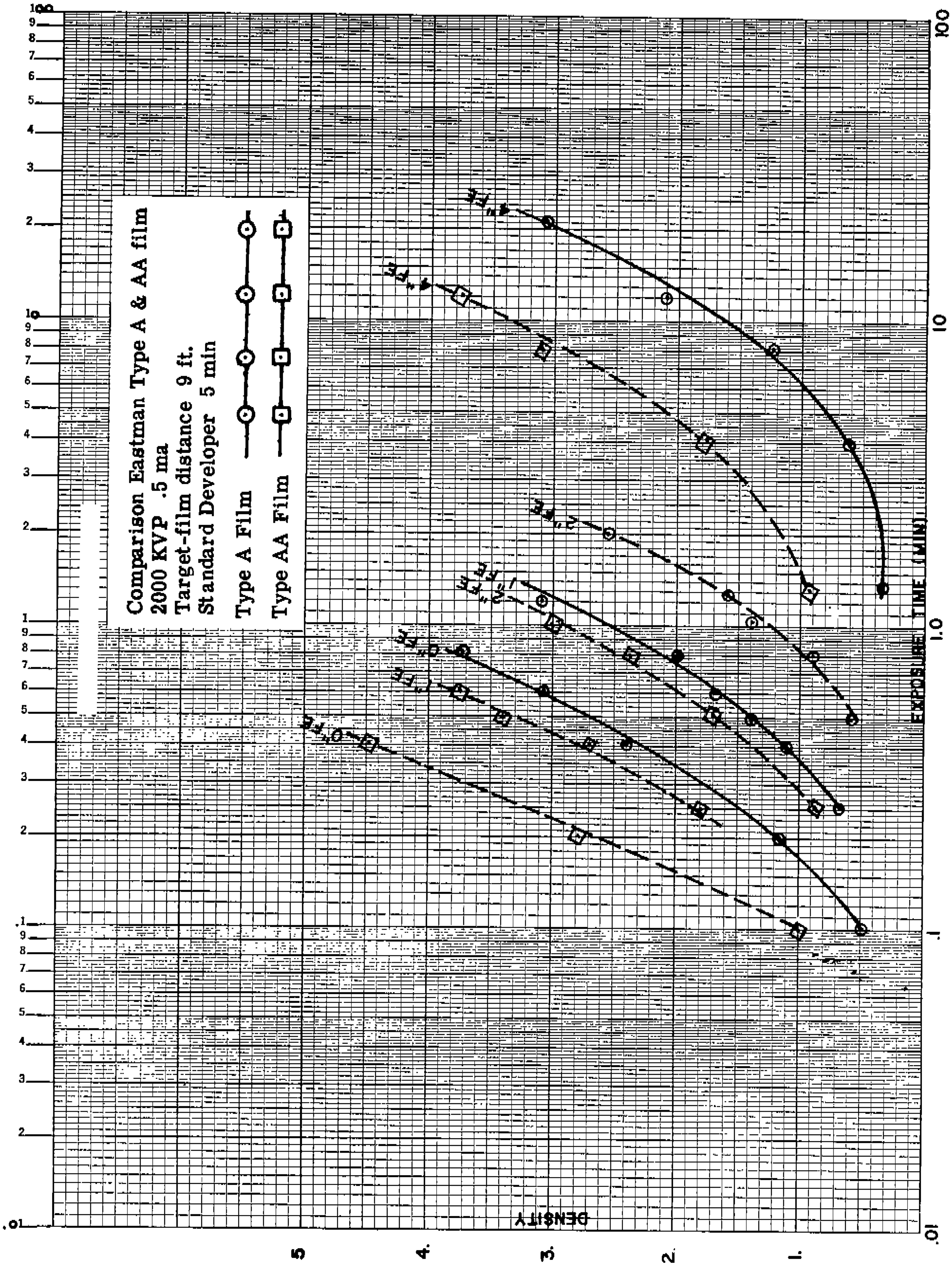

Comparison Eastman Type A & AA film
2000 KVP .5 ma
Target-film distance 9 ft.
Standard Developer 5 min
Type A Film
Type AA Film
EXPOSURE TIME (MIN)
DENSITY

Chart No. 32

APPENDIX A

Glossary of Terms

half life:	The time required for a radioactive substance to lose 50 per cent of its activity.
output:	A term loosely used to indicate the ionization produced by an isotope or an X-ray machine.
specific activity:	The total radioactivity of a given isotope per gram of the element.
rhm (roentgen/ hr a 1 m):	Abbreviated form of expressing roentgens per hour at one meter which is a dose rate.
HVL:	(half value layer) That thickness of material which will reduce the radiation intensity by one half.
energy:	Energy of radiation is expressed in terms of million electron volts.
MeV:	Million electron volts. The energy gained by an electron in passing through a potential difference of one million volts.
bremsstrahlung:	The radiation produced by the slowing down and stopping of charged particles passing through matter.
curie:	The quantity of an isotope disintegrating at the rate of 3.7×10^{10} atoms per second. The curie is based on the disintegration rate of 1 gram of radium.
roentgen:	A measure of the ionization produced by radiation. The quantity of X or gamma radiation such that the associated corpuscular emission per 0.001293 grams of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign.

mr: An abbreviated form for milliroentgen. It is one thousandth of a roentgen.

radiographic technique (exposure, etc.): The method by which the radiograph was made. The exposure time, target to film distance, and energy of radiation used, are usually listed.

exposure factor: Exposure factor is defined by the equation $EF = \frac{T x \ mrhm}{D^2}$
where T = time of exposure in minutes
mrhm = milliroentgens per hour at one meter
D = target to film distance in inches.

penetrameter: A small strip of metal with three drilled holes made of the same material as that being X rayed. The standard penetrameter is two per cent of the thickness of the material being examined. The diameter of the hole sizes vary from two per cent to eight per cent of the thickness being examined.

sensitivity (%): The quality of a radiograph as expressed by a penetrameter which is a certain percentage of the thickness of the material being investigated.

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