SSC-121

MANUAL OF ISOTOPE RADIOGRAPHY

by

E. L. Criscuolo
D. Polansky
and
C. H. Dyer

SHIP STRUCTURE COMMITTEE

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ADDRESS CORRESPONDENCE TO:

SECRETARY
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WASHINGTON 25, D. C.

May 23, 1960

Dear Sir:

As part of its research program related to the fabrication of hull structures of ships, the Ship Structure Committee sponsored a study at the Naval Ordnance Laboratory to prepare a manual to guide field workers in the techniques involved in the use of four selected gamma ray sources for detecting flaws in welded engineering structures. Herewith is a copy of SSC-121, "Manual of Isotope Radiography," by E. L. Criscuolo, D. Polansky and C. H. Dyer.

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.

Sincerely yours,

E. H. Thiele
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

Serial No. SSC-121

Final Report
of
Project SR-127

to the

SHIP STRUCTURE COMMITTEE

on

MANUAL OF ISOTOPE RADIOGRAPHY

by

E. L. Criscuolo, D. Polansky and C. H. Dyer

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
May 23, 1960

PREFACE

The purpose of this manual is to present information and experimental data on the radiography of steel (particularly welds) using isotopes. This information will assist the radiographer in selecting the proper technique. The technique described can be applied to the radiographic inspection of welds contained in ship structures. No attempt is made in this document to evaluate the discontinuities other than to familiarize the reader with the interpretation and classification of defects.

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INTRODUCTION

The development of industrial radiography has centered around such available radiation sources as X-ray machines and radium. Light-weight portable X-ray machines and radioactive isotopes have extended the applicability of radiography. Isotopes, because of their low cost and wide energy range, have, to a large extent, displaced radium. The information contained in this report will assist in the proper selection of isotopes and the estimation of exposure time for a given material.

CHARACTERISTICS OF GAMMA RAYS

Gamma rays are penetrating rays of nuclear origin. They differ from high-energy X-rays only in their origin and therefore have the same valuable characteristics as X-rays. Those characteristics of gamma rays which are of particular interest in industrial radiography include their being:

1. differentially absorbed by all material,
2. able to ionize matter,
3. capable of blackening photographic film,
4. propagated in straight lines, and
5. not affected by electric or magnetic fields.

Absorption

Gamma rays are absorbed in material in accordance with the absorption formula:

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

where I_o is the initial radiation intensity, I the transmitted radiation intensity after penetrating the material, x the material thickness, μ the linear absorption coefficient, and e is 2.718. The linear absorption coefficient μ is defined as the fractional reduction in intensity per unit length of material. Although the value of this coefficient varies with different materials as well as with different amounts of radiation energy for the same material, each material has a constant μ at any particular energy level. Thus it can be seen from the absorption formula that there will be one thickness of material that will reduce the initial radiation intensity by one-half. That is, when

$$\frac{I}{I_o} = \frac{1}{2}$$

then

$$\frac{1}{2} = e^{-\mu x_{1/2}}$$

$$\ln 2 = \mu x_{1/2}$$

$$x_{1/2} = \frac{\ln 2}{\mu} = \frac{.693}{\mu}$$

This thickness of material ($x_{1/2}$) is called the half-value layer (HVL) for the particular material and energy and is useful in the calculation of exposure times and identifying unknown sources.

The energy of X or γ-radiation is measured in electron volts (ev), thousand electron volts (kev), or million electron volts (Mev). An electron volt is defined as the energy of an electron that has been accelerated by a potential of one volt. Thus an X-ray machine operated at one hundred thousand volts accelerates the electrons to the energy of 100 KeV. Those electrons that strike the target in the tube and are stopped emit X-rays that have a peak energy of 100 KeV. In general, the higher the energy of the radiation, the greater is its ability to penetrate material.

Table I lists the half-value layers and energies of the most common isotopes used in radiography, thulium (Tm 170), iridium (Ir 192), cesium (Cs 137) cobalt (Co 60) and radium (Ra 226). It can be seen that for iron or mild steel the HVL increases with increasing energy. Also there is a difference in HVLs for iron and lead, the lead having the greater ability to "stop" the radiation. This agrees with the fact that materials with higher densities and atomic numbers have smaller HVLs. For alloy steels and other materials, the HVLs can be obtained by means of the previous formula.

<u>Ionization</u>

Gamma rays in their interaction with matter produce ionization; that

TABLE I

CHARACTERISTICS OF ISOTOPES USED IN RADIOGRAPHY

	Tm^{170}	Ir^{192}	Cs^{137}	Co^{60}	Ra^{226}
Average Energy (Mev)	.083	.28	.66	1.25	1.7
Production Process	Pile Produced	Pile Produced	Fission Product	Pile Produced	Mined & Refined
Half Life	125 days	74 days	37 years	5.3 years	1590 years
HVL* Lead (in.)	.060**	--	.39	.47	.51
HVL* Iron or mild steel	.42***	.52	.67	.75	.80
Radiation output rhm/curie	45×10^{-3}	.55	.39	1.32	.84

*Measured value broad beam
**Initial HVL
***Large thickness HVL

is, particles of matter attain a plus or minus charge. This is the primary means by which radiation is detected and measured. If a volume is irradiated, some of the electrons are knocked away from an atom so that we have free electrons available. If these electrons are attracted to a positively charged anode, which may be located centrally in the volume of gas, we will have a current flow. Current flow gives an indication of the amount of radiation incident upon the volume of gas. This method of radiation detection is used in ionization chambers.

Film Blackening by Gamma Rays

Gamma rays cause film blackening in much the same manner as light. When film is exposed to gamma rays, a latent image is produced, which, upon development, is made visible. Radiography makes use of this important characteristic. Gamma rays absorbed in the emulsion produce development centers in the silver halide crystal. The development centers are tiny particles of metallic silver within the crystal. The development process will reduce this whole crystal to metallic silver, thus developing the latent image. The film characteristic and development procedure will be treated in a later section.

Effect of Electric and Magnetic Fields

Industrial radiography can be carried out under practically any environmental condition because local electric or magnetic fields have no effect on gamma radiation. The propagation of radiation in straight lines allows the exposure to be arranged in the simplest possible geometry: gamma source-object-film in a straight line.

Isotopes

Elements with the same atomic number but with different atomic weights are called isotopes. Some isotopes are stable; others are unstable or radioactive. A radioactive isotope is one in which the nuclei of the atoms disintegrate. The disintegration (decay) of the nuclei proceeds with the emission of alpha or beta particles; accompanying this decay, generally with the beta particle, is a gamma ray. It is those isotopes that emit gamma rays that are of value in radiography.

The decay of an isotope is purely random, and the number of disintegrations per second is proportional to the amount of radioactive material present. This leads to a decay formula similar to the absorption formula described earlier:

$$N = N_o e^{-\tau t}$$

where N is the number of disintegrations per unit time, N_o the number of radioactive atoms present at t = o, τ the decay constant, t the time, and e is 2.718.

In a manner analogous to that described for finding the half-value layer we can find a time such that the number of radioactive atoms remaining is one-half the original amount. This length of time T is called the half-life of the isotope. Since the number of disintegrations per unit time is proportional to the amount of radioactive material present, the radiation

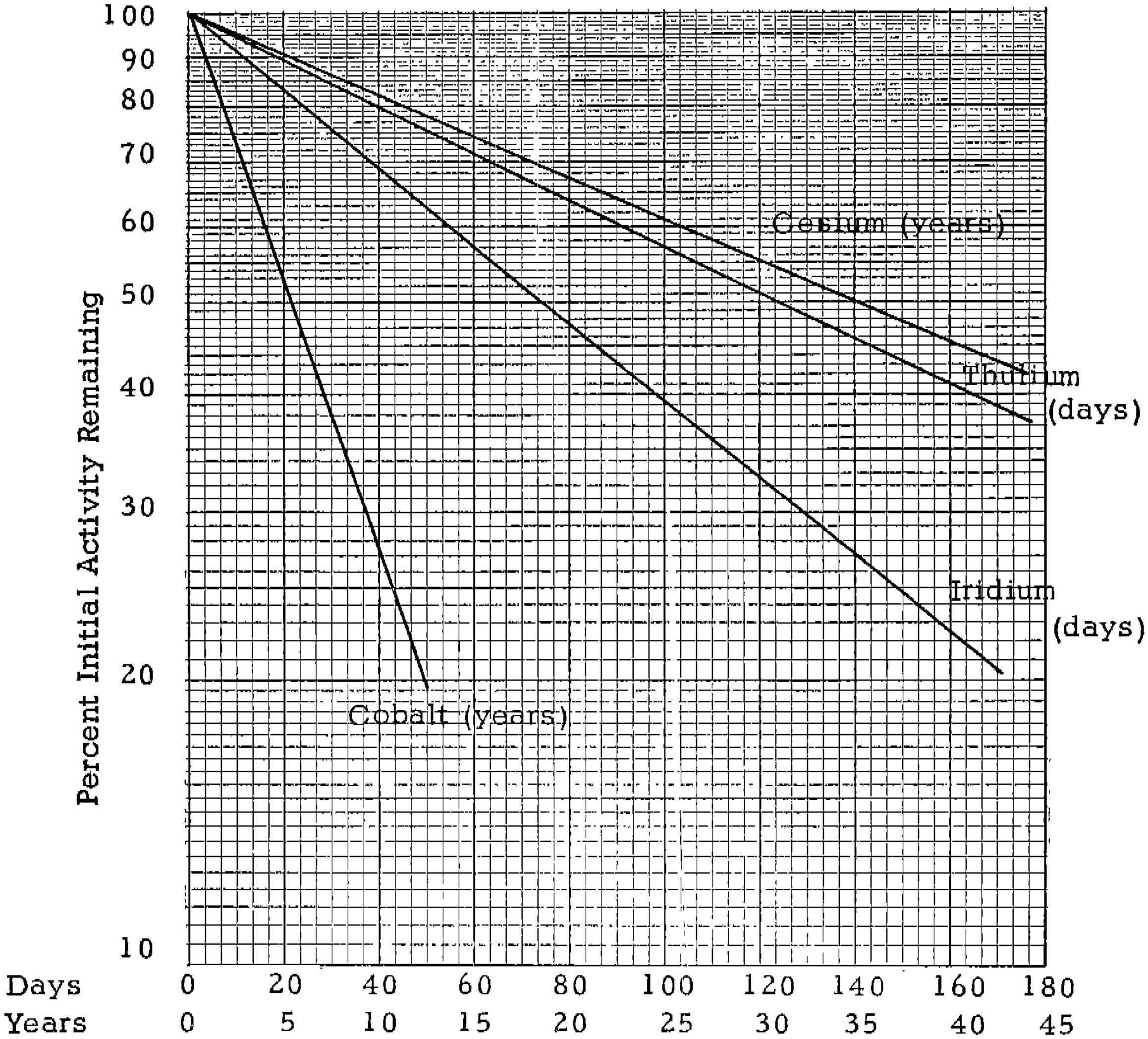

Fig. 1. Decay curves for cesium, thulium, iridium and cobalt.

output is also halved in the time T. The activity of a radioactive source is measured by its disintegration rate. The curie is the unit of measurement of source activity and is defined as the quantity of any radioactive material that has a disintegration rate of 3.7×10^{10} disintegrations/sec. Radiation is measured in roentgens per time, and one method of measuring source strength is by specifying the radiation output in roentgens per hour at one meter.

Table I gives the half-lives and the radiation outputs of the isotopes commonly used in radiography, while Fig. 1 is a graph of the decay curves of the isotopes. An example illustrating the use of Fig. 1 follows: Consider a two-curie source of Cobalt 60 which has an output of 2.64 roentgens/hr at one meter; three years later the source will have decayed to 67% of its original value. This is equivalent to 1.34 curies and will have an output of 1.77 roentgens/hr at one meter.

FILM CHARACTERISTICS

X-ray film consists of a silver halide emulsion placed upon both sides of a clear safety base sheet. Radiation absorbed by the emulsion makes the silver halide grains developable. When a film is developed, those areas that absorbed radiation are dark, while those that absorbed less radiation are lighter. The "darkness" of a film is measured in units of density. Density is defined as the logarithm of the ratio of the incident light on the film to the emergent light ($D = \log \frac{I_o}{I_1}$). For example, a density of one indicates that the incident light on a film is ten times more intense than the emergent light, while a density of 1.3 indicates that the incident light is 20 times more intense than the emergent light.

The density of darkness on a film is dependent on the exposure time. A plot of the density versus log exposure, which gives the characteristic curve of the exposed film, is shown in Fig. 2. From curves of this type, one can determine the change in exposure time to get a given change in density, determine the relative speeds between different films, and, by the slope of the curve, determine which film will give the highest contrast at a given density. The slope of the straight line portion of a characteristic curve is called the film gradient. Satisfactory industrial radiographs vary in density from about 1.2 to 3.0, although the best sensitivity is obtained at a density of about 2.5.

The speed of a film is the reciprocal of the time required to get an arbitrary density on the film. In general, each film manufacturer selects one of his films as speed 100 and bases the speed of his other types of film relative to the arbitrary film. For example, Eastman Kodak rates Type A film a speed of 100, Type M film as 30, and Type AA as 200, when they are used with high-energy radiation.

RADIOGRAPHIC TECHNIQUES

The radiographic procedure consists of four steps--setup, exposure, development, and interpretation. Each of these steps will be considered separately.

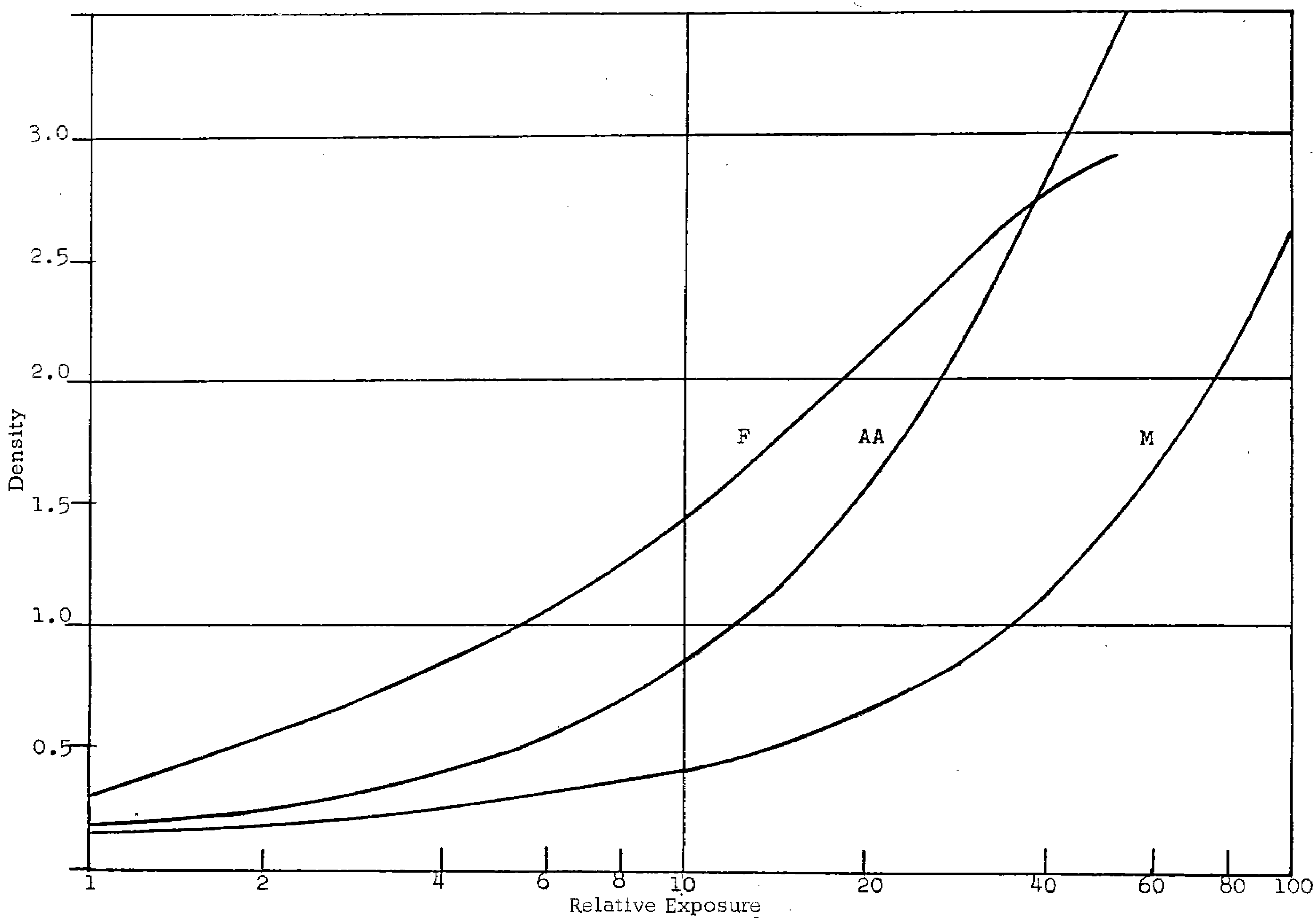

Fig. 2. Characteristic curves Eastman F, AA, and M Film

Setup

The setup includes all the preliminary steps before actually making the exposure, such as the selection of film and screen combination, source, source-to-film distance, filter and scatter precautions.

The selection of film and screens usually depends upon the resolution required in the radiograph and the length of exposure that can be tolerated. The characteristics of several industrial X-ray films are given in Table II. Slow-speed film, such as Eastman Type M, du Pont 510, Ansco Superay B, or equivalent, is generally used on reactor components, aircraft parts, and critical welds.

TABLE II

INDUSTRIAL X-RAY FILMS OF SIMILAR CHARACTERISTICS

Contrast	Grain	Speed	Ansco	du Pont	Eastman
High	Fine	Slow	Superay B	510	M
High	Medium	Medium	Superay A	506	AA
Medium	Coarse	Fast	Superay C	508	K
Medium	Coarse	Very fast	*High Speed	504*	F*

*When used with calcium tungstate screens

The primary function of the intensifying screen is to reduce the exposure time. The screens are placed on each side of the film inside the holder or cassette. When irradiated, lead screens eject photoelectrons which are captured by the film, thus producing increased blackening of the developed film. For radiography with isotopes, lead screen thicknesses of .005-in. front and .010-in. back are commonly used.

The chemical screens depend upon the emission of light for intensification. A calcium tungstate screen, when used with screen-type film such as Eastman F, Ansco high speed, or du Pont 504, reduces exposure time by as much as 30 times.

The selection of the proper radioactive isotope is important in producing a good radiograph. Those sources of greatest interest are Tm 170, Ir 192, Cs 137, and Co 60. A good rule for the selection of an isotope for inspection of a given thickness of material is to choose a source whose half-value layer thickness is 1/3 to 1/6 times the section thickness. The HVL for steel with Co 60 is about 0.75 in., and 3 in. represents 4 half-value layers; therefore Co 60 is satisfactory.

The source-to-film distance is another factor to consider. Since the image on the film is formed by geometrical projection, the source size and distances will determine the geometrical unsharpness. A large distance will result in a very long exposure time; a too-short distance will produce an unsharp image. Figure 3 shows the geometry involved in the proper setup. The source size, distance of the object from the film, and the source-film distance are factors related in the following manner:

$$\text{Unsharpness} = \frac{\text{object-to-film distance} \times \text{source size}}{\text{source-object distance}}$$

For optimum resolution, the unsharpness owing to geometry should be equal to or less than the film unsharpness.

For example, a radiographic setup is to be made with Co 60 to inspect 2 in. of steel at a distance of 2 ft. The source size is a 1/8-in. cube. The film unsharpness is .003 in. (Type AA film). Is the geometrical resolution satisfactory in this setup?

$$\text{Unsharpness} = \frac{2 \text{ in.}}{22 \text{ in.}} \times (.125 \text{ in.})$$

$$= .011 \text{ in.}$$

Since the film unsharpness is less than the geometrical unsharpness, the source-to-film distance should be increased for improved resolution. Typical values of film unsharpness are given in Table III.

Another consideration is scatter, a complicated subject of which only a brief discussion will be given here. Scatter originates primarily from two sources--from the room, benches, and setup (room scatter) and from the object (forward

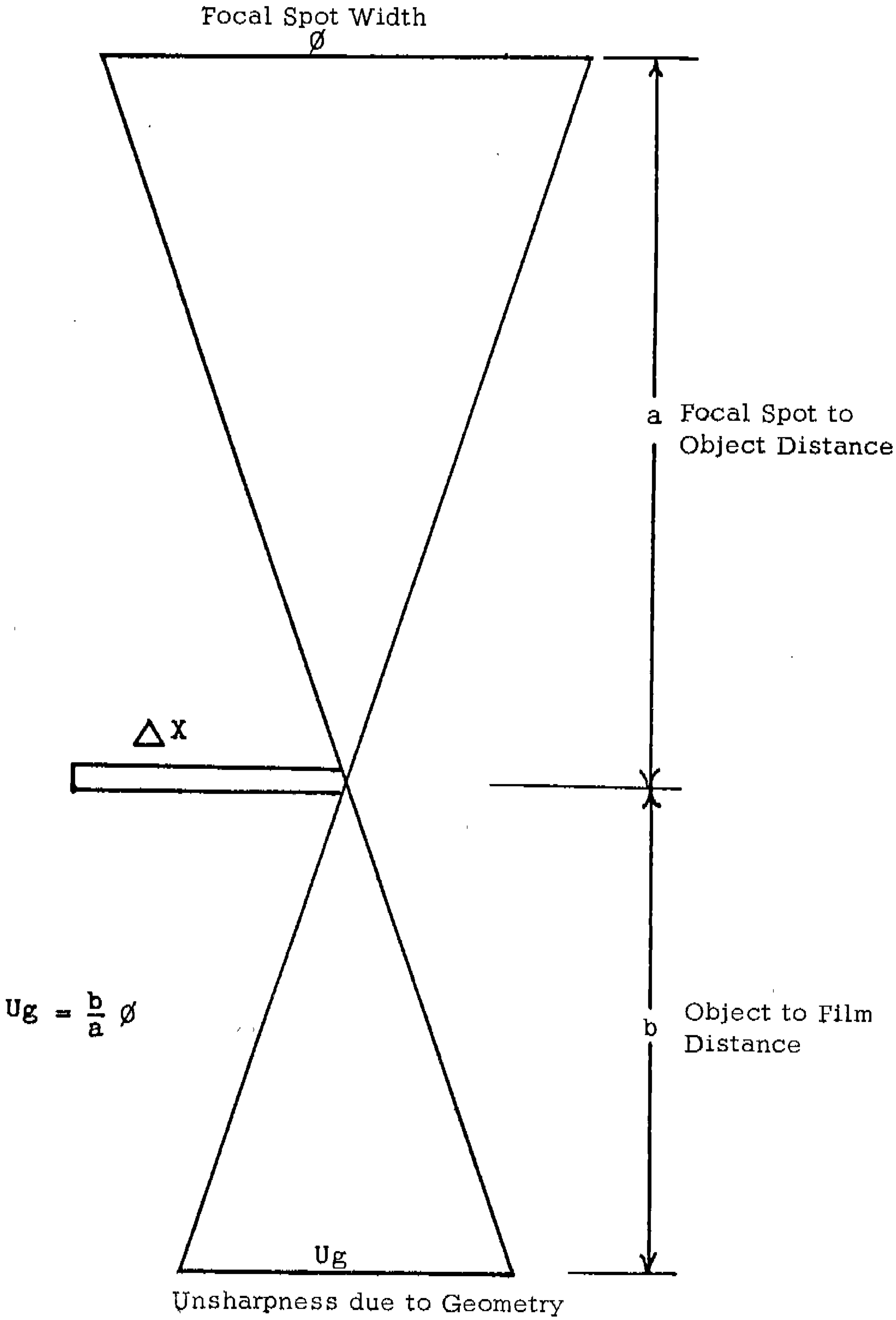

Fig. 3. Line diagram showing the geometry for a radiographic set-up.

TABLE III
INHERENT UNSHARPNESS OF FILM AND SCREENS[1]
Co 60 - 1-in. Steel

Film	Screen	Unsharpness (in.)
Eastman Type A or AA	None	.002
Eastman Type A	Lead	.003
Eastman Type F*	None	.005
Eastman Type F*	Patterson 245	.028

*1/4-in. lead filter used

scatter). Scatter tends to fog the film, thus reducing contrast. In almost any setup, there is a certain amount of radiation being scattered from the wall, ceiling, and floor of a room. Room scatter can be minimized (a) by irradiating only the pertinent area so that little radiation reflects off the wall, and (b) by shielding the film (placing lead behind it) to avoid back scatter from the floor. With Tm 170 and Ir 192, a 1/4-in. back lead is sufficient, whereas 1/2 in. is necessary for Cs 137 and Co 60.

Scatter from the object can be prevented from reaching the film by placing a lead filter of the proper thickness over the film which will differentially filter the scattered radiation and allow the primary radiation to penetrate. A .030-in. lead filter for Ir 192 and a 1/8-in. or 1/4-in. for Co 60 are commonly used.

Estimation of Exposure Time

An accurate estimation of exposure time is very important with isotopes since the time involved is usually long compared to exposures made with X-ray equipment. The opportunity for a second exposure may not always occur. There are approximately three ways of estimating exposures: (1) by technique and sensitivity curves, (2) by calculation, and (3) by radiation measurements.

Exposure calculators are also available and eliminate the need for calculation. They are a convenient form of the technique curve.

In estimating the exposure time, the shape of the object must be considered. If the object is a flat plate of known and uniform thickness, it is simple to estimate the exposure time. An object with varying thickness is a bit more difficult to estimate because the exposure for each thickness must be considered. Some complex objects will require two or more exposures for complete coverage.

Technique and Sensitivity Curves. The technique curve is the easiest method of determining exposure time if the section thickness and material are known. This curve is a plot of exposure as a function of thickness on semi-log paper (Fig. 4). If a radiograph of 2 in. of steel is to be made with one curie of Co 60 to obtain a density of 1.5, the exposure time is determined in the following manner: first, locate the point on the 1.5 density technique curve that corresponds to 2 in. of steel. From this point, the exposure factor, 125, on the ordinate can be located. The exposure factor may be used as a relative guide or it may be used with the following formula which considers source strength and distance:

$$\underset{\text{(minutes)}}{\text{Exposure time}} = \frac{\text{Exposure factor} \times \text{distance (in.}^2\text{)}}{\text{source strength (milliroentgens/hr at 1 m)}}$$

From Table I, it can be seen that one curie of Co 60 produces 1.32 roentgens/hr at one meter or 1320 milliroentgens/hr. Inserting the values in the formula, the exposure time (in minutes) can be calculated as follows:

Exposure factor = 125

Source strength = 1320 milliroentgens/hr at 1 m

Distance = 30 in.

$$t = \frac{125\,(30)(30)}{1320}$$

$$t = 85 \text{ min.}$$

Technique charts 1 to 23 for various isotopes can be found at the end of this report. These charts also include sensitivity loops which define an area on the chart where a given sensitivity can be obtained. Sensitivity is a meas-

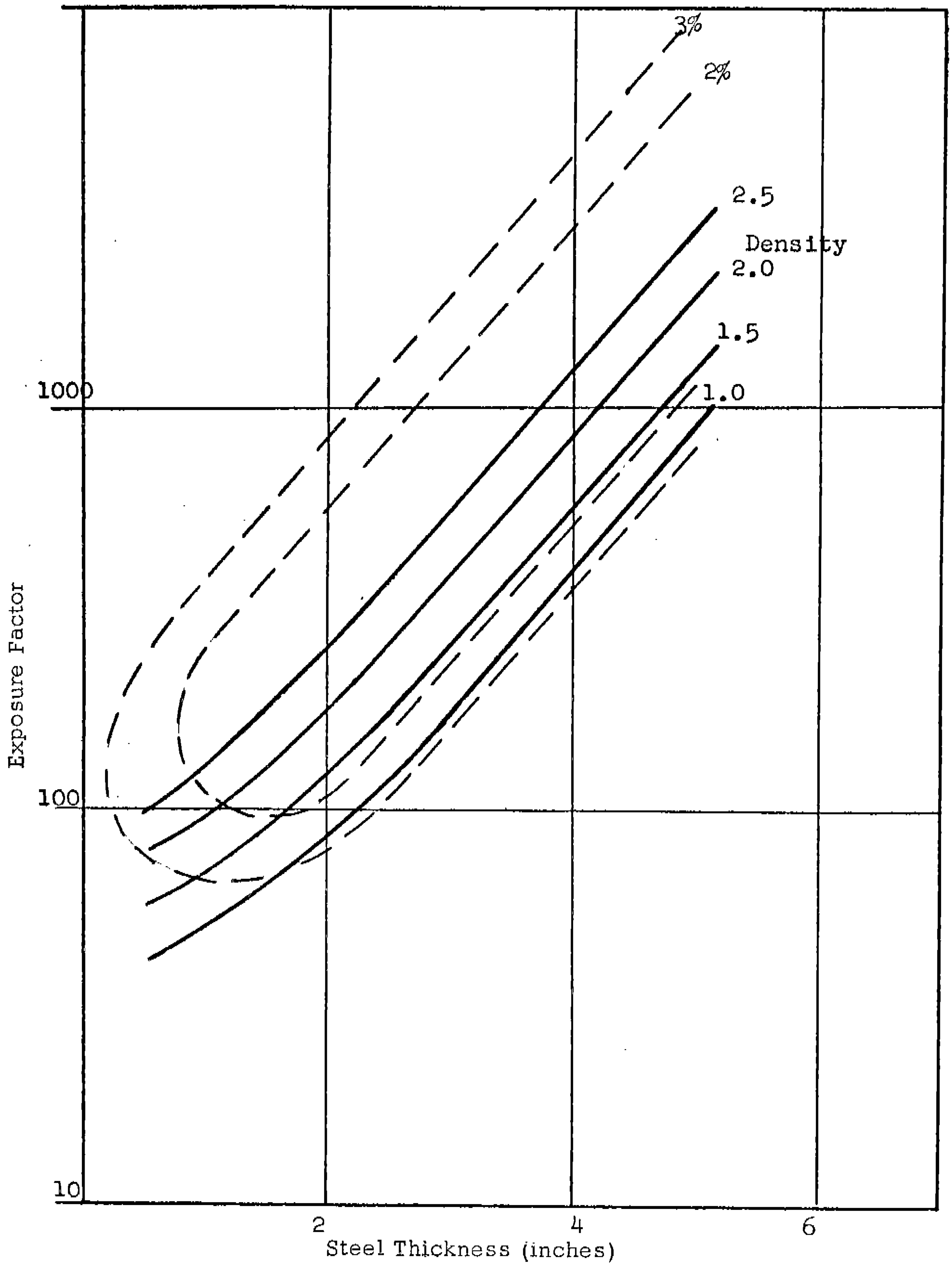

Fig. 4. Sample technique and sensitivity curves used in determining exposure time.

ure of film quality and is indicated by the visibility of a hole in a penetrameter. The penetrameter is a small strip of material that is radiographically similar to the material being X-rayed* and contains three holes, whose diameters are one, two and four times the thickness of the penetrameter. The penetrameter thickness expressed as a percentage of the total thickness of the material being radiographed is defined as sensitivity. The penetrameter is marked with a number that indicates the thickness of material for which the penetrameter represents 2% sensitivity. For example, if an object to be X-rayed is 1 in. thick, what penetrameters should be used to indicate 1 and 2% sensitivity? For 1% sensitivity, one uses a penetrameter usually marked with "0.5" which is .010 in. thick (1% of 1 in.). For 2% sensitivity, a penetramenter marked "1" is used. This penetrameter thickness is .020 in. (2% of 1 in.).

Calculations of Exposure Time. A quick calculation can be made by estimating the attenuation of the X-ray beam as it passes through a given thickness of absorber. The sensitivity of the film is then used to obtain the exposure time to produce the density desired.

The half-value layer has previously been defined as the thickness of material that will reduce a given initial radiation intensity to one-half. This value will vary a little as a function of thickness but is almost constant beyond the second or third half-value layers. From the half-value layer figures in Table I the transmitted radiation intensity per unit of source output is obtained for any thickness of the material by using one-half raised to the power of the number of half-value layers represented by the absorber thickness. For example, if the absorber thickness is 1.5 in. and the half-value layer is .5 in., then the number of half-value layers is 1.5 divided by .5 or 3. The transmitted radiation intensity would then be $(1/2)^3$ or 1/8 the initial intensity. The sensitivity of the film is given in Table IV.

A typical example for calculating the exposure time to produce a film density of 2.0, given a Co 60 source, output of 2 roentgens/hr at one meter, an iron absorber thickness of 4.5 in., a distance of 1 m, and a film AA, follows:

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*ASTM specification E 142 - 59T

TABLE IV

EXPOSURES IN ROENTGENS FOR HEAVILY FILTERED CESIUM AND COBALT RADIATION

Film	Density 1	2	3
AA	.35	0.8	1.3
M	2.5	5	9.3

From Table I, the HVL for iron with Co 60 is .75 in.; therefore $\frac{4.5 \text{ in.}}{.75 \text{ in.}}$ = 6 half-value layers. The transmitted radiation intensity per unit of source output for this thickness is

$$\left(\frac{1}{2}\right)^6 = \frac{1}{64}$$

The output of source after passing through iron is then 2/64 rhm, and from Table IV, 0.8 is required to produce a film density of 2. Therefore the exposure time is

$$\frac{.8}{2/64} = 25.6 \text{ hr}$$

The above calculation was made for a source-film distance of one meter. If a distance of other than one meter is used, the output of the source would have to be calculated for the source-film distance being used.

The inverse square law states that the intensity of radiation is inversely proportional to the square of the distance:

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2$$

where d_1 is the original distance, d_2 the new distance, I_1 the original intensity, and I_2 the new intensity. If 5 roentgens/hr is obtained at 1 m, the intensity at 3 m is

$$\frac{5}{I_2} = \left(\frac{3}{1}\right)^2$$

$$I_2 = \frac{5}{9} \text{ roentgens/hr}$$

Estimation of Exposure Times by Radiation Measurement. Another method of estimating exposure time is by direct measurement. If a survey meter or other type of detector is used behind the objects to measure the intensity of radiation, then the exposure time may be estimated very accurately. After a reading is made in roentgens or milliroentgens/hr, and the number of roentgens it takes to produce a given density on the film is known, then the exposure time necessary to produce the required density may be calculated. For example, if an intensity of 50 milliroentgen/hr is transmitted through the object and .8 roentgens is required to produce the proper film density, then the exposure time is .8 divided by .050 roentgens/hr (50 milliroentgens/hr) or 16 hr.

This method is satisfactory where the radiation intensity is low. In areas where a high radiation level exists, a remote reading-type dosimeter should be used. In any case, care should be used in applying this method because of the possible danger of excessive radiation exposure to personnel.

DEVELOPMENT PROCEDURES

Film should be developed according to standard procedures as published by ASTM in E94-52T, Tentative Recommended Practice for Radiographic Testing, or according to manufacturers' recommendations. Reasonable care in processing of film will ensure the highest quality radiograph.

The processing cycle for radiographs includes X-ray developer, rinse, stop, fixer, and wash. A typical cycle might be to develop for 5 min. at 68 F (8 min. for maximum speed), rinse 15 sec in clear water, place for 30 sec in the stop bath, fix for 5-10 min., and then wash in running water for about 30 min. After washing, the film may be placed in an emulsion hardening bath for about 1 min. Film should be dried by a forced draft of air.

It is during the developing cycle while the emulsion is soft that care should be taken to see that the films do not contact each other and that handling of the film is at a minimum. Poor procedure during developing will result in film blemishes that may appear as defects or may mask actual defects in the material radiographed.

INTERPRETATION OF RADIOGRAPHS

General

Interpretation is an important step of radiographic inspection. The interpreter must be given a set of standards and/or reference radiographs by which an evaluation of the object can be made. Familiarity with the material inspected, radiographic procedure, and service requirements are necessary before an intelligent evaluation can be made.

Film Viewing Procedure

An important piece of equipment used by an interpreter is the viewer. Two types are necessary--a large screen and a high-brightness spot viewer. Some manufacturers make these combined into one unit with a dial to control the intensity of the spot light. Another device which is useful in the viewing room is a small magnifier of approximately 7X. This is made in several styles in which the reticle contains scales, lines, and/or different size circles for ease in measurement.

A few procedures that should be followed when viewing film are:

a. View film in a darkened room. A dim sidelight for notetaking is permissible.

b. Illuminate the film area only (avoid glare).

c. Use spot viewer for dense areas.

d. Keep films clean.

The first thing that an interpreter looks for on a radiograph is the penetrameter. This device will indicate if the technique is satisfactory. Secondly, a comparison is made to the radiographic standard to accept or reject the specimen. A record of the findings is made for future reference.

Standards

Numerous standards have been developed during the past twenty years for castings and weldments of aluminum, magnesium, steel, and bronze. In these standards, a discontinuity is illustrated in varying degrees of severity.

The product specification usually defines which degree is acceptable. In practice, the interpreter makes a comparison to the standard and makes a decision to accept or reject the specimen part. The terminology used by most standards to describe discontinuities in castings and weldments is given in ASTM E52-49T and is as follows:

1. Gas

   1.1 Gas Holes
   1.2 Gas Porosity

2. Shrinkage

   2.1 Shrinkage Cavity
   2.2 Shrinkage Porosity or Sponge
   2.3 Micro-shrinkage

3. Heterogeneities

   3.1 Foreign Materials
   3.2 Segregations

4. Sharp Discontinuities

   4.1 Hot Cracks
   4.2 Cold Cracks
   4.3 Cold Shut

5. Miscellaneous

   5.1 Surface Irregularities
   5.2 Misruns
   5.3 Core Shift

6. Weld Discontinuities

   6.1a Inadequate Penetration
   6.1b Incomplete Fusion
   6.2 Undercut
   6.3 Porosity
   6.4 Slag
   6.5 Cracks

Below is a list of ASTM and Military Standards:

E71-52, Radiographic, Industrial Standards for Steel Castings.
X-ray Radiographic Standards, Set of 31 plates in binder.
Gamma Ray Radiographic Standards, Set of 31 plates in binder.
E98-53T, Radiographs, Reference for Inspection of Aluminum and Magnesium Castings.

E99-55T, Reference Radiographs for Steel Welds.
NAVSHIP 250-537-1, Radiographic Standards for Bronze Castings.
NAVSHIP 250-692-2, X-ray Standards for Production and Repair Welds.
MIL-R-11468, Radiographic Inspection; Soundness Requirements for Arc and Gas Welds in Steel.
MIL-R-11469, Radiographic Inspection; Soundness Requirements for Steel Castings.
OD-7574, X-ray Standards for Shielded Arc Welds in Aluminum, Parts I and II.

Many times the film interpreter will find defects that will cause rejection or necessitate repair of completed work. At times he will be called upon to substantiate his findings. The use of film standards and ASTM terminology give the film interpreter a solid foundation for his decisions.

The value of radiographic inspection is not only to reject defective parts but also to assist in the production of higher quality material. For example, in the inspection of ship welds, the radiographer may find the first indication of poor quality by noting porosity or other discontinuities in the welds. A conference between radiographer and welder should be held, and this "defect" can be corrected by the welder. Occasional conferences between welder and radiographer should assure the welder that radiography is used to assist him. With or without radiography, welders today produce high quality welds most of the time. It is the function of radiography to detect any discontinuities and determine whether they are of significance for the specific application.

RADIATION SAFETY

The characteristics of X-rays and gamma rays that make them useful for industrial inspection are the same characteristics that make them dangerous to the human body. The ability of radiation to penetrate large masses of material and to ionize matter can result in damage to the body. This problem of radiation injury has been recognized since the early days of X-rays. Recent advances in nuclear technology have emphasized and enlarged the problem so that considerable work has been done on the subject of radiation safety. Groups such as the National Bureau of Standards, the Atomic Energy Commission, the Public Health Service, the National Committee on Radiation Protection, and many others have published very valuable data on radiation safety.

A few of the basic safety guides will be mentioned here. Detailed information can and should be obtained from the references listed at the end of this report.

General

The unit of dose is the roentgen. Table V lists the present basic maximum permissible dose per week. This dose is further limited by the present recommendation that the yearly dose should not exceed 5 roentgens, thus giving an average weekly maximum permissible dose of 100 milliroentgens. The basic approach of people working with radiation should be that any unnecessary radiation exposure, no matter how small, is too much. Obviously, exposure resulting from carelessness and bad habits can only lead to overexposure and should be assiduously avoided.

TABLE V

PERMISSIBLE WEEKLY DOSE FOR BLOOD FORMING ORGANS, GONADS AND EYES

Radiation	R.B.E.*	Rems*	Rads or Roentgens
X-rays 0.1 to 100 Mev	1	0.3	0.3
Electrons 0.1 to 100 Mev	1	0.3	0.3
Photons up to 10 Mev	10	0.3	0.03
Neutrons-thermal to 10 Mev	10	0.3	0.03
Alpha particles	10-20	0.3	0.03-0.015

*See glossary

Methods of Protection

There are two simple means of minimizing exposure to radiation--shielding and distance. For field calculations, the inverse square law is a good guide, that is, doubling the distance between radiation source and object reduces the intensity (dose rate) to one-fourth of its original value. Thus, in the use of isotopes in the field, the radiation area can be roped off to prevent accidental exposure.

The effectiveness of material as shielding is based on its atomic number and density. The measured value of this effectiveness is expressed in terms of half-value layers. Lead, with its high atomic number, is an excellent and relatively inexpensive shielding material.

Table VI lists the half-value layers for different gamma ray energies. As can be seen from the table, radiation intensities can be reduced with considerably less thickness of lead than the other materials listed. It is by the use of these simple methods, shielding and inverse square law, that the radiographer can minimize the radiation received either by himself or nearby workers.

TABLE VI

SHIELDING HALF-VALUE LAYERS[2]

Energy (Mev)	Half-Value Layer (in.)			
	Water	Concrete	Steel	Lead
0.5	2.91	1.46	0.425	0.159
0.8	3.60	1.76	0.533	0.273
1.0	4.00	1.96	0.597	0.350
1.5	4.85	2.49	0.744	0.478
2.0	5.59	2.99	0.894	0.573

Radiation Monitoring

Radiation monitoring of an area is accomplished with the use of instruments either based on the ionization produced in a given volume of air (Cutie Pie Meter) or the response of crystals to radiation (crystals that fluoresce and whose light output is then measured). These instruments should be used during field exposures to determine the extent of the radiation field that may require roping.

Personnel monitoring is done with the use of film badges and/or pocket dosimeters. Film badges are of practically universal use. They integrate the dose received and thus give an excellent record of the total exposure received by a person. Film badge service is available to small groups by many reputable laboratories listed in the scientific journals.

The self-reading pocket dosimeter is generally used in conjunction with the film badge on a specific job where it is necessary to know the dose received during progress of the work. Dosimeters for this use are generally in the 0-200 mr range. Pocket dosimeters of higher ranges are available, although these are designed for high-radiation fields--much higher than normally experienced.

Care of Radioactive Capsules

The radioactive material contained in a metal capsule is considered a sealed source. Rupture of the capsule may result in contamination of surrounding area and personnel. In order to check the condition of the capsule, periodic wipe tests are made. This test consists of wiping the source container with a piece of cotton and then checking the cotton with a survey meter to determine whether it has been contaminated. For cesium and some cobalt sources, AEC Regulations[3] require a wipe test once every six months. If a leaker is detected, steps should be taken to prevent spread of the contamination and the proper authorities should be notified.

Conclusions

Shielding and distance are the simple measures to minimize exposure that can be observed in work with radiation. People working with radiation should be required to wear film badges. Radiation survey meters should be available to survey the area and to allay the fears of the uninformed who must come near the area. Establishment of standard procedures should be required of persons working with radiation. Information such as is contained in the references listed at the end of this report should be available and made required reading by operating personnel.

GLOSSARY

Roentgen:

The roentgen is defined as that quantity of X- or gamma-radiation which results in the associated corpuscular emission per 0.001293 gram of air producing in air ions carrying one electrostatic unit of charge of either sign.

Rad:

The unit of absorbed dose, which is 100 ergs/gram.

Roentgen Equivalent Man:

That quantity of ionizing radiation which, when absorbed by man, produces an effect equivalent to the absorption by man of one roentgen of X- or gamma-radiation (400 KVP).

Relative Biological Effectiveness:

The rates of gamma- or X-ray dose to the dose that is required to produce the same biological effect by the radiation in question.

Maximum Permissible Dose:

That dose of ionizing radiation that, in the light of present knowledge, is not expected to cause detectable bodily injury to a person at any time during his lifetime.

rhm (roentgen/hr at 1 m):

Abbreviated form of expressing roentgens per hour at one meter which is a dose rate.

REFERENCES

1. Hirschfield, J. J., O'Connor, and Polansky, D., Gamma Ray Sources and Techniques for Gamma Ray Radiography (NAVORD Report 2666). Washington: Naval Ordnance Laboratory.

2. General Handbook for Radiation Monitoring (LA 1835). Los Alamos, New Mexico: Los Alamos Scientific Laboratory.

3. Standards for Protection Against Radiation, 10 CFR, Part 20, Jan. 20 and Amendment of May 14, 1957.

GENERAL REFERENCES

1. X-ray Protection (Handbook 60). Washington: National Bureau of Standards.

2. Permissible Dose for External Sources of Ionizing Radiation (Handbook 59). Washington: National Bureau of Standards.

3. Photographic Dosimetry of X- and Gamma Rays (Handbook 57). Washington: National Bureau of Standards.

4. Kinsman, S., ed., Radiological Health Handbook. Cincinnati, Ohio: Sanitary Engineering Center, U. S. Department of Health, Education and Welfare.

5. Radiological Safety Regulations (NAVMED P-1325). Washington: Bureau of Medicine and Surgery, U. S. Department of the Navy.

6. "Recommendations of the International Commission on Radiological Protection" (Supplement No. 6), British Journal of Radiology, 1955.

7. Frazier, P. M., Buchanan, C. R., and Morgan, G. W., Radiation Safety in Industrial Radiography with Radioisotopes (AECU-2967). Washington: Atomic Energy Commission, 1954.

8. Information on Licensing of Industrial Radiography Programs (AEC Publication RC-17). Washington: Atomic Energy Commission.

TECHNIQUE AND SENSITIVITY CURVES

Chart No.	Description
1	Th 170, M film, Lead screens, No filter.
2	Th 170, M film, Lead screens, .030" lead filter.
3	Th 170, F film, Lead screens, No filter.
4	Th 170, F film, Lead screens, .030" lead filter.
5	Th 170, F film, Patterson 245 screens, No filter.
6	Th 170, F film, Patterson 245 screens, .030" lead filter.
7	Ir 192, M film, Lead screens, No filter.
8	Ir 192, M film, Lead screens, .030" lead filter.
9	Ir 192, AA film, Lead screens, No filter.
10	Ir 192, AA film, Lead screens, .030" lead filter.
11	Ir 192, F film, Lead screens, No filter.
12	Ir 192, F film, Lead screens, .030" lead filter.
13	Ir 192, F film, Calcium tungstate screens, No filter.
14	Ir 192, F film, Patterson 245 screens, .030" lead filter.
15	Cs 137, M film, Lead screens, No filter.
16	Cs 137, M film, Lead screens, .125" lead filter.
17	Cs 137, AA film, Lead screens, No filter.
18	Cs 137, AA film, Lead screens, .125" lead filter.
19	Cs 137, F film, Lead screens, .125" lead filter.
20	Cs 137, F film, Calcium tungstate screens, .25" lead filter.
21	Co 60, AA film, Lead screens, No filter.
22	Co 60, F film, Lead screens, .25" lead filter.
23	Co 60, F film, Calcium tungstate screens, .25" lead filter.

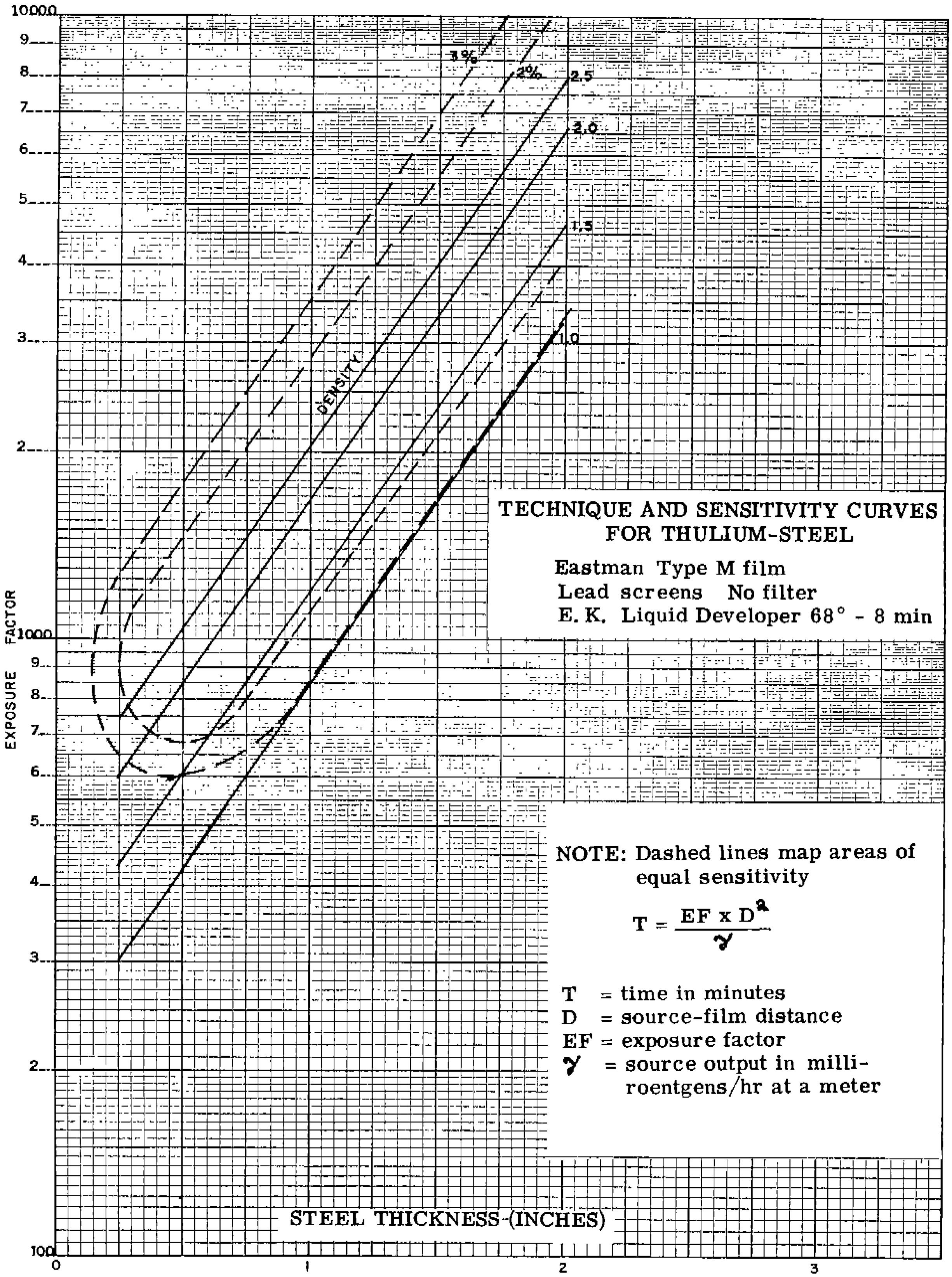

TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type M film
Lead screens No filter
E. K. Liquid Developer 68° - 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in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

Chart No. 1

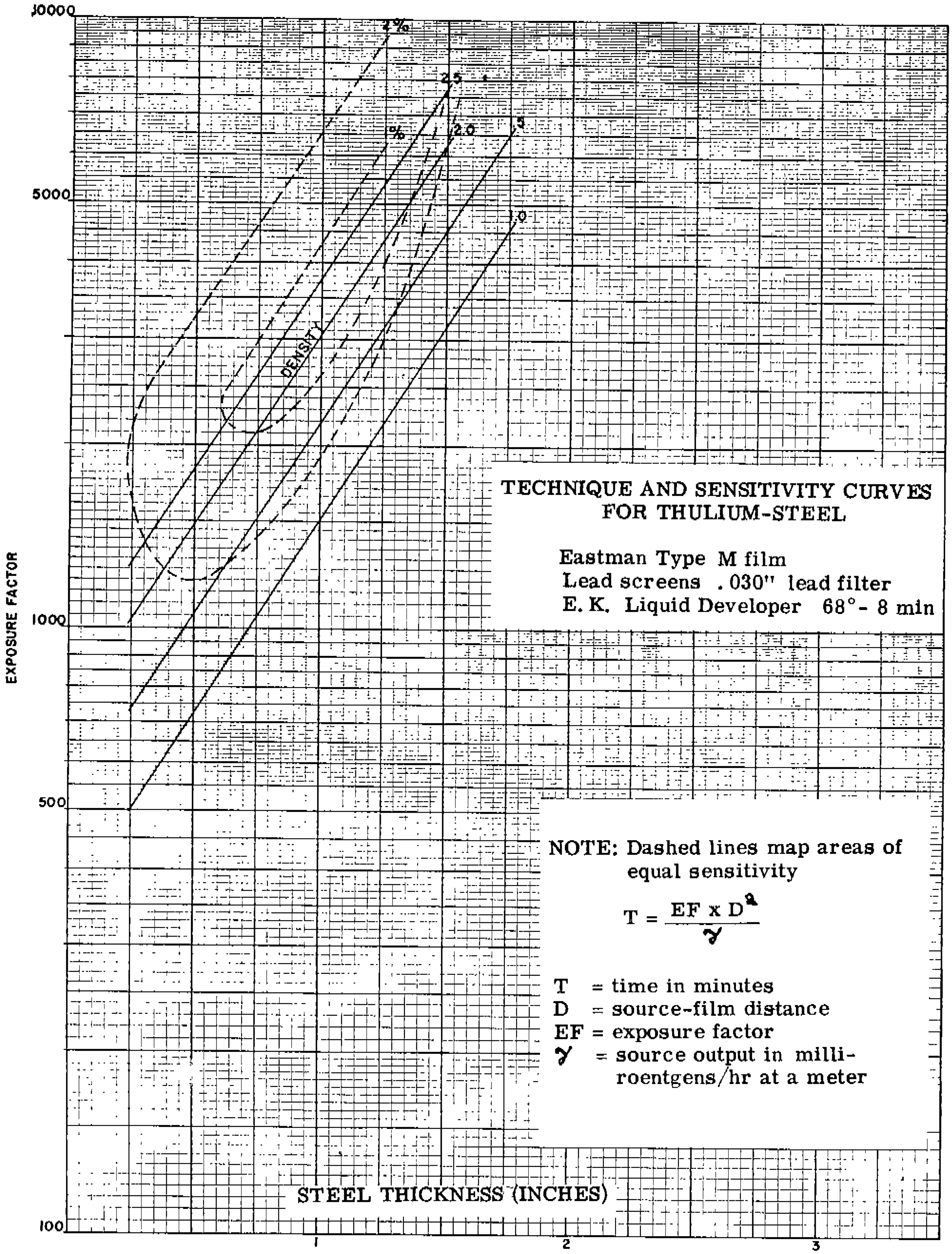
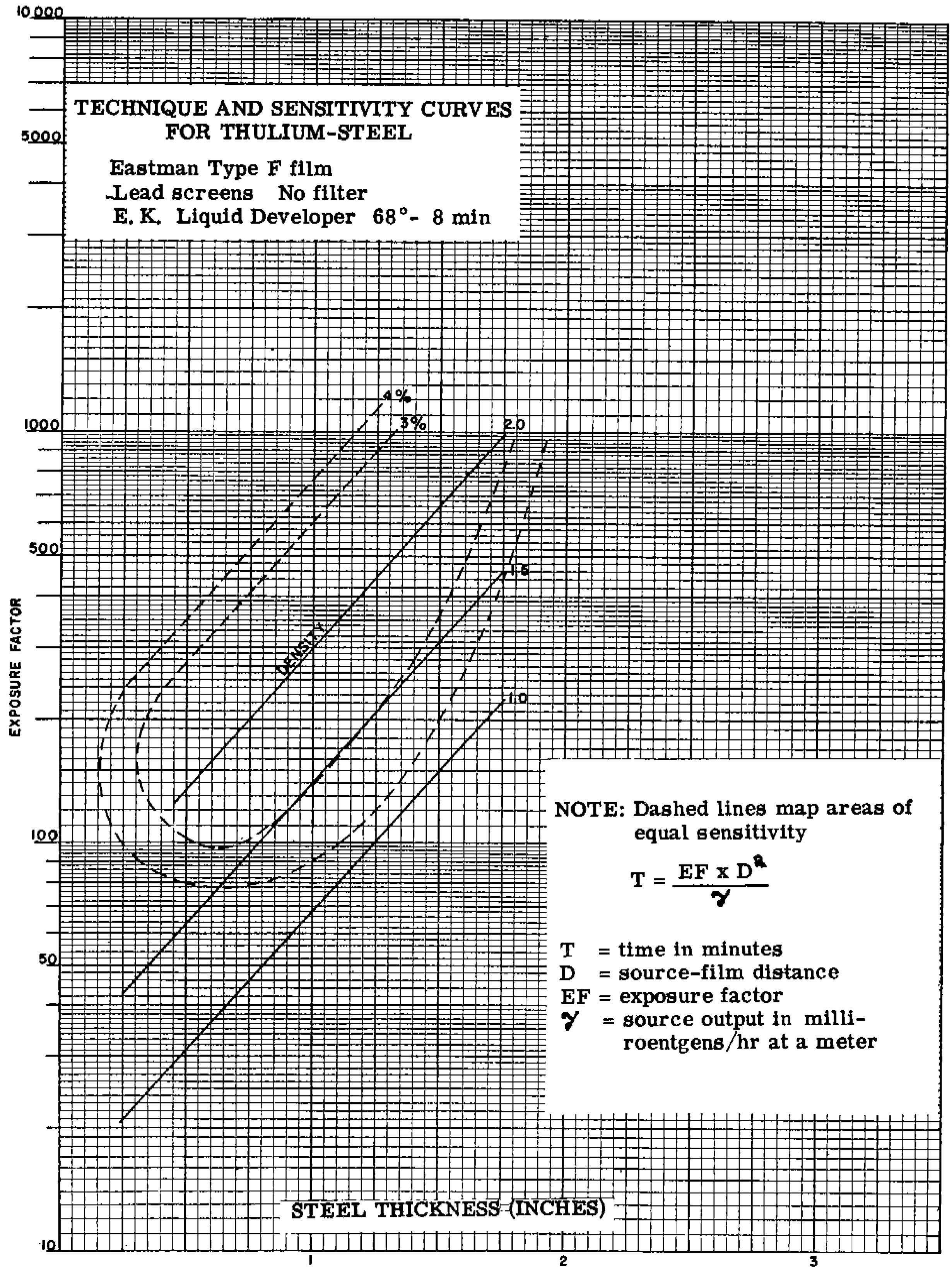

TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type M film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output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

Chart No. 2



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 = 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
4%
3%
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
10,000
5000
1000
500
100
50
10
1
2
3

Chart No. 3

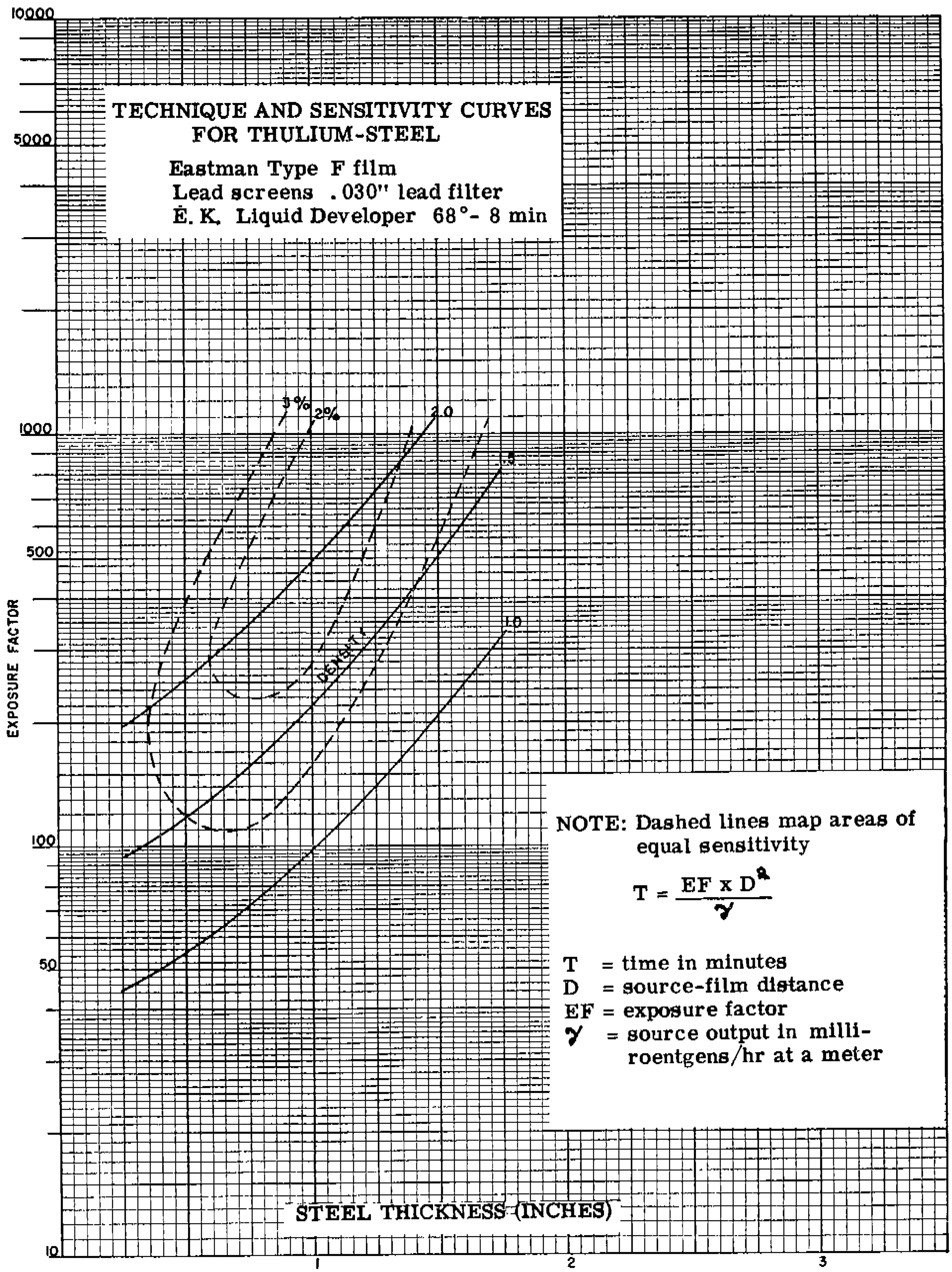

TECHNIQUE AND SENSITIVITY CURVES
FOR THULIUM-STEEL
Eastman Type F film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
EXPOSURE FACTOR
10000
5000
1000
500
100
50
10
3%
2%
2.0
1.5
1.0
DENSITY
STEEL THICKNESS (INCHES)
1
2
3
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 4

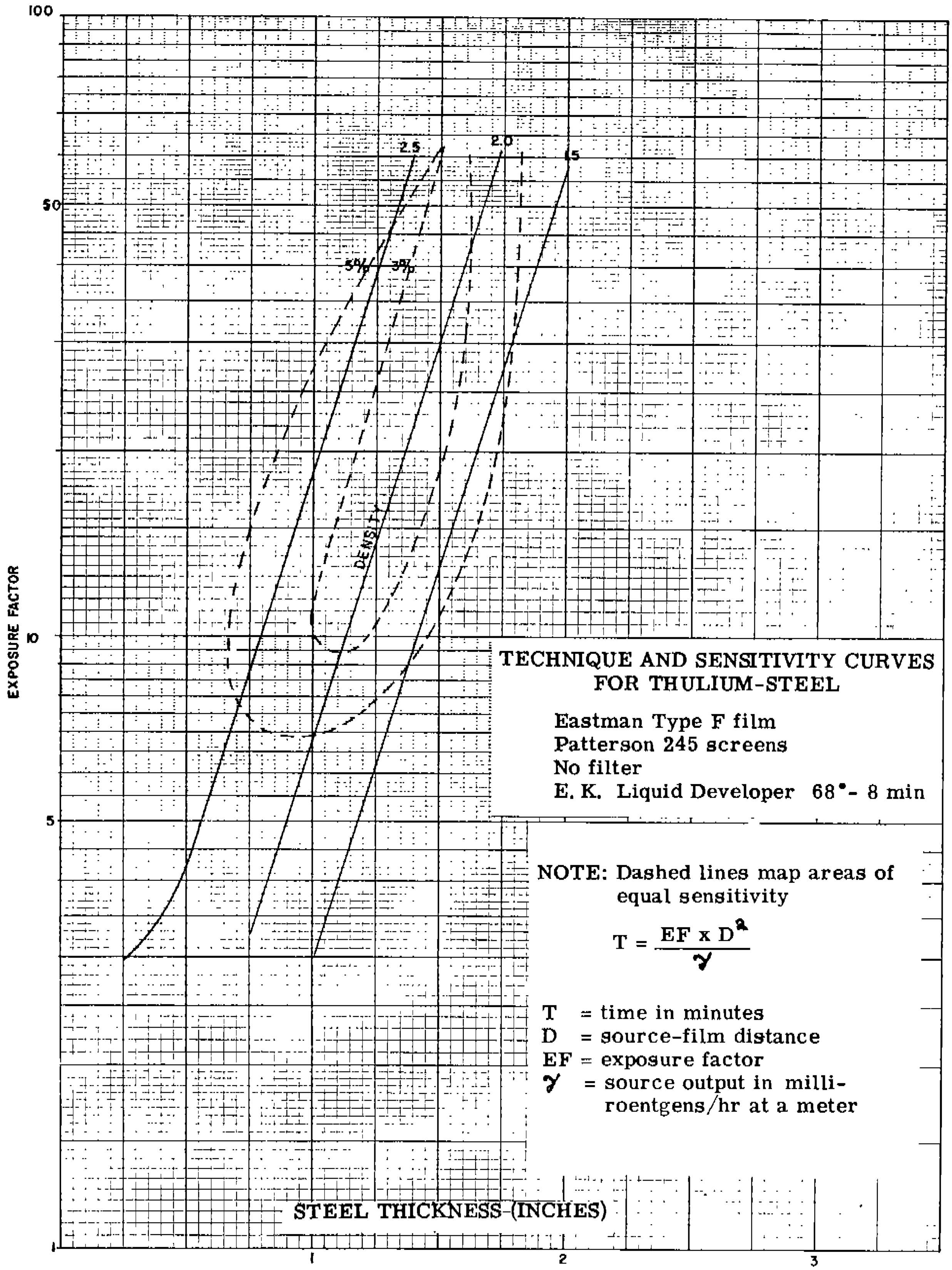

100
50
10
5
1
EXPOSURE FACTOR
2.5
2.0
1.5
5%
3%
DENSITY
1
2
3
STEEL THICKNESS (INCHES)
TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type F film
Patterson 245 screens
No filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter

Chart No. 5

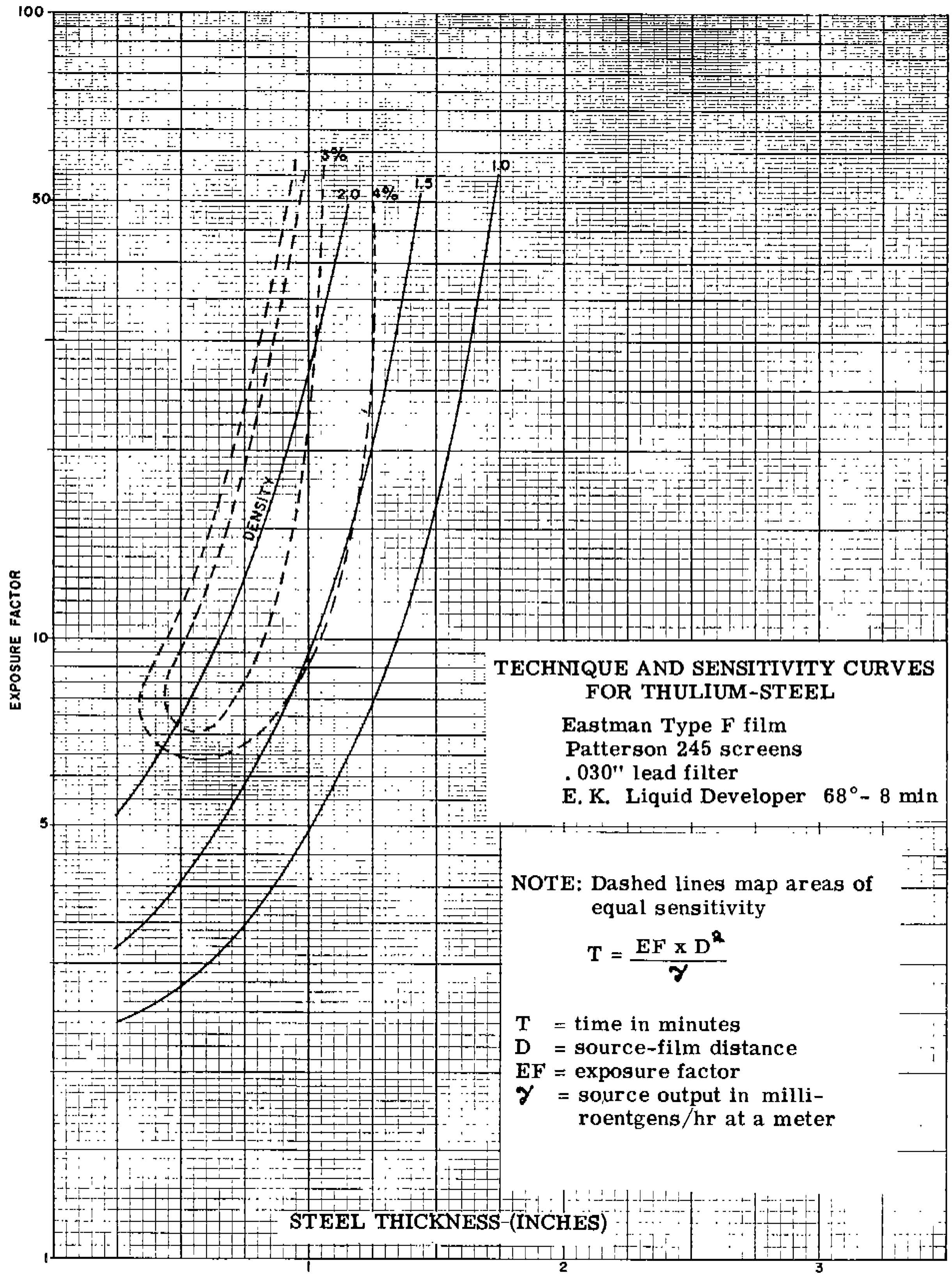
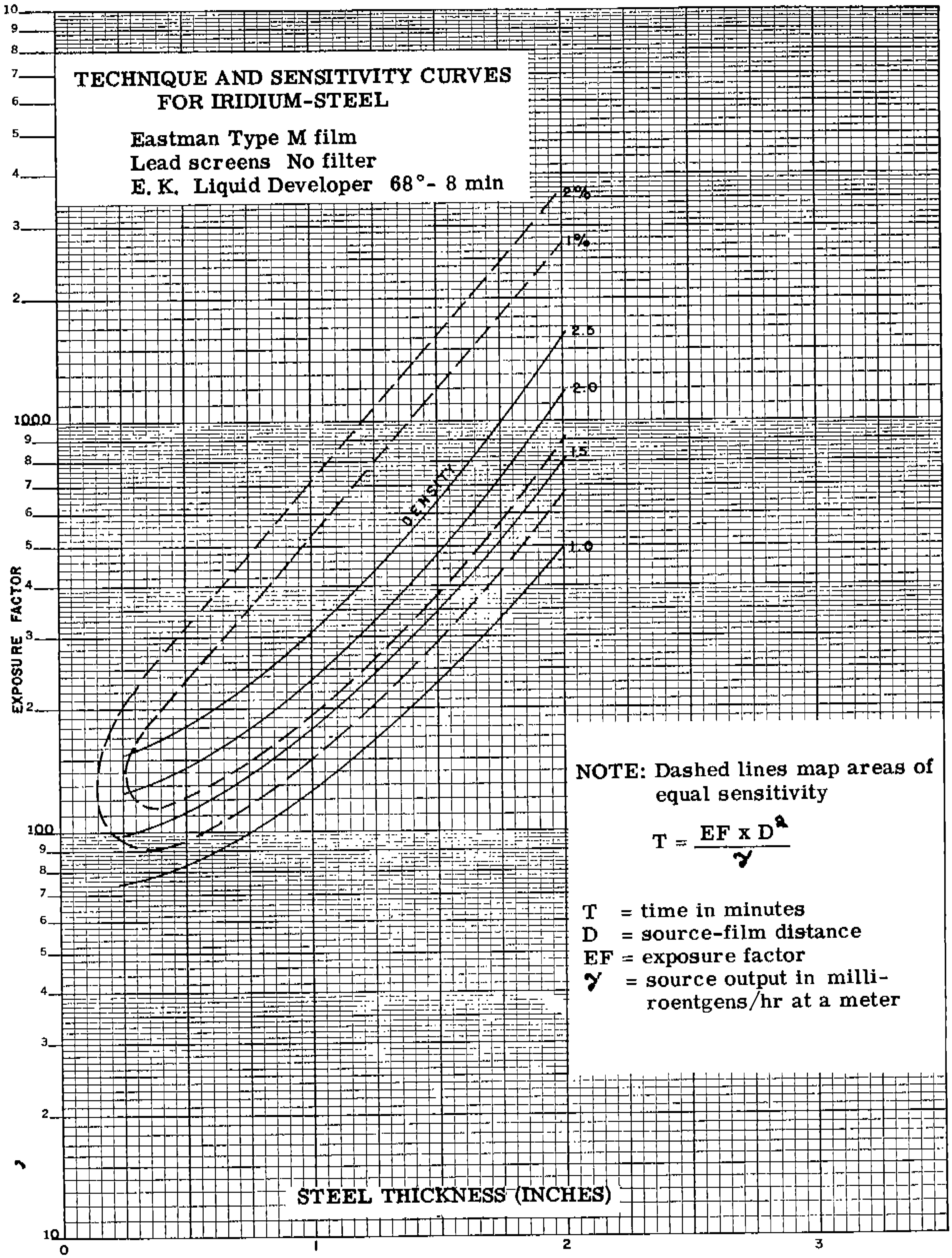
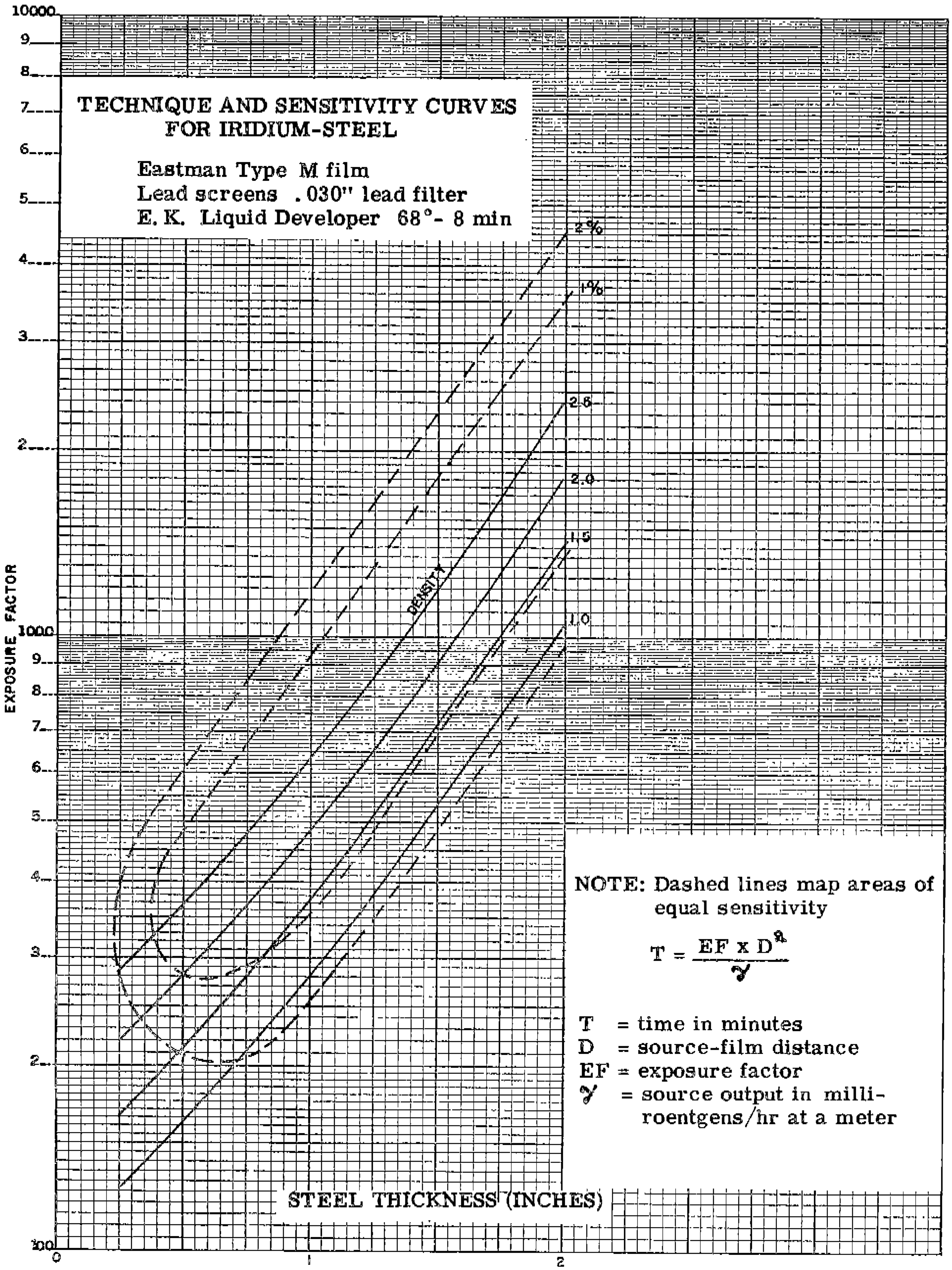

100
50
10
5
1
EXPOSURE FACTOR
1
3%
2.0
4%
1.5
1.0
DENSITY
TECHNIQUE AND SENSITIVITY CURVES FOR THULIUM-STEEL
Eastman Type F film
Patterson 245 screens
.030" lead filter
E. K. Liquid Developer 68°- 8 min
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes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

Chart No. 6



TECHNIQUE AND SENSITIVITY CURVES FOR IRIDIUM-STEEL
Eastman Type M film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
2%
1%
2.5
2.0
1.5
1.0
DENSITY
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
STEEL THICKNESS (INCHES)

Chart No. 7



TECHNIQUE AND SENSITIVITY CURVES FOR IRIDIUM-STEEL
Eastman Type M film
Lead screens .030" lead filter
E. K. Liquid Developer 68°- 8 min
2%
1%
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
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 milli-roentgens/hr at a meter

Chart No. 8

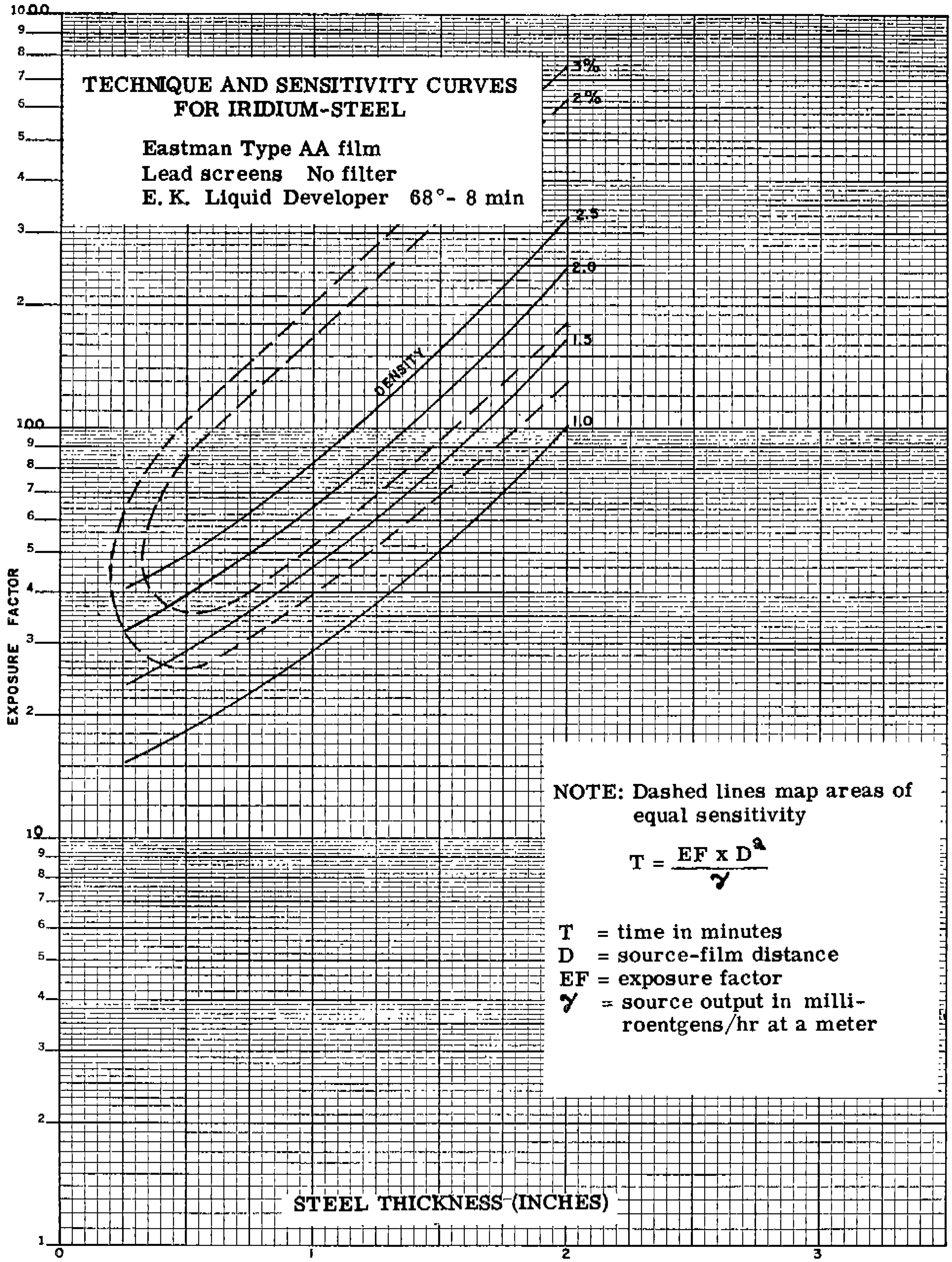
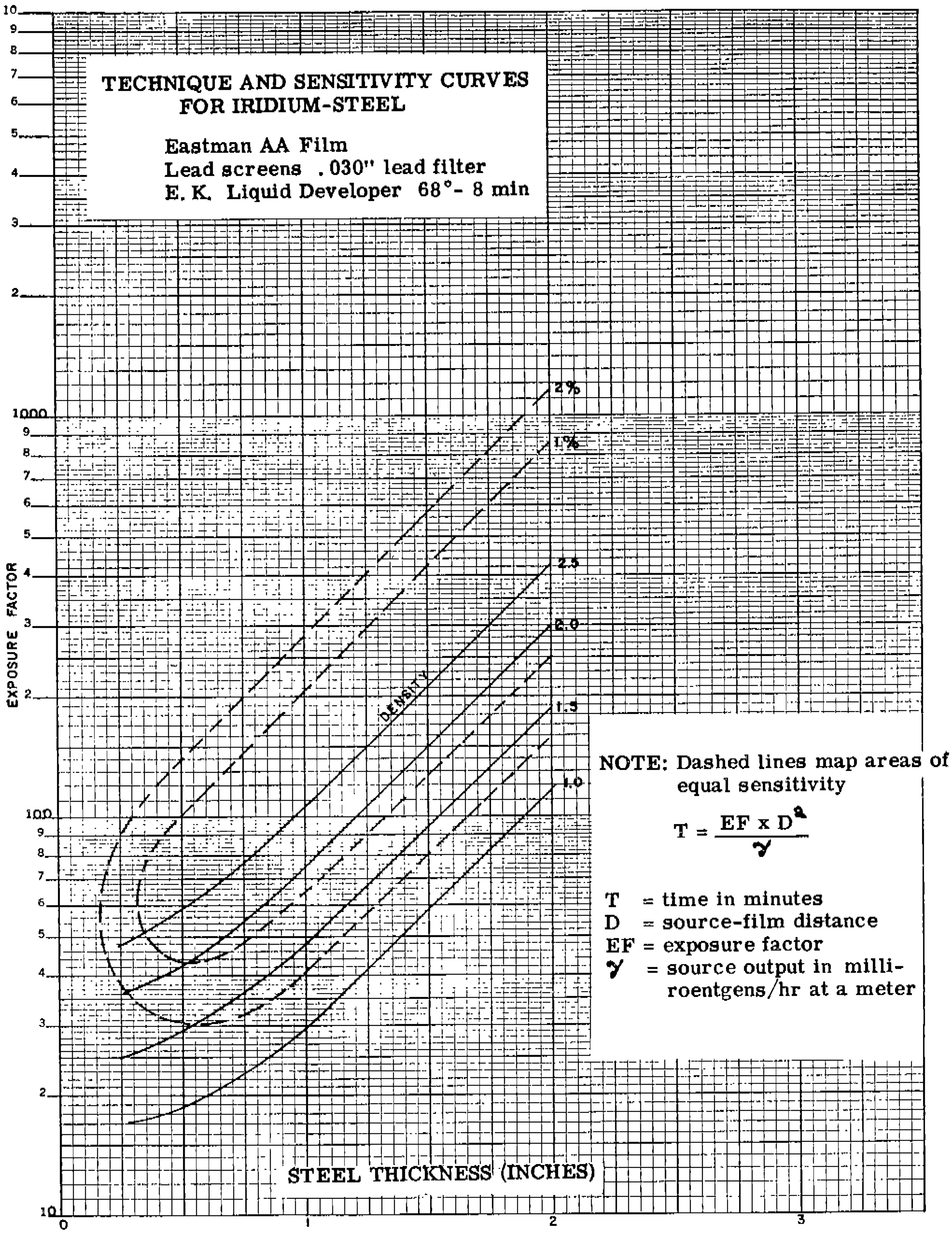

TECHNIQUE AND SENSITIVITY CURVES
FOR IRIDIUM-STEEL
Eastman Type AA film
Lead screens No filter
E. K. Liquid Developer 68°- 8 min
3%
2%
2.5
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
1000
100
10
1
STEEL THICKNESS (INCHES)
0
1
2
3
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$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

Chart No. 9



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 milliroentgens/hr at a meter
10
1000
100
10
0
1
2
3

Chart No. 10

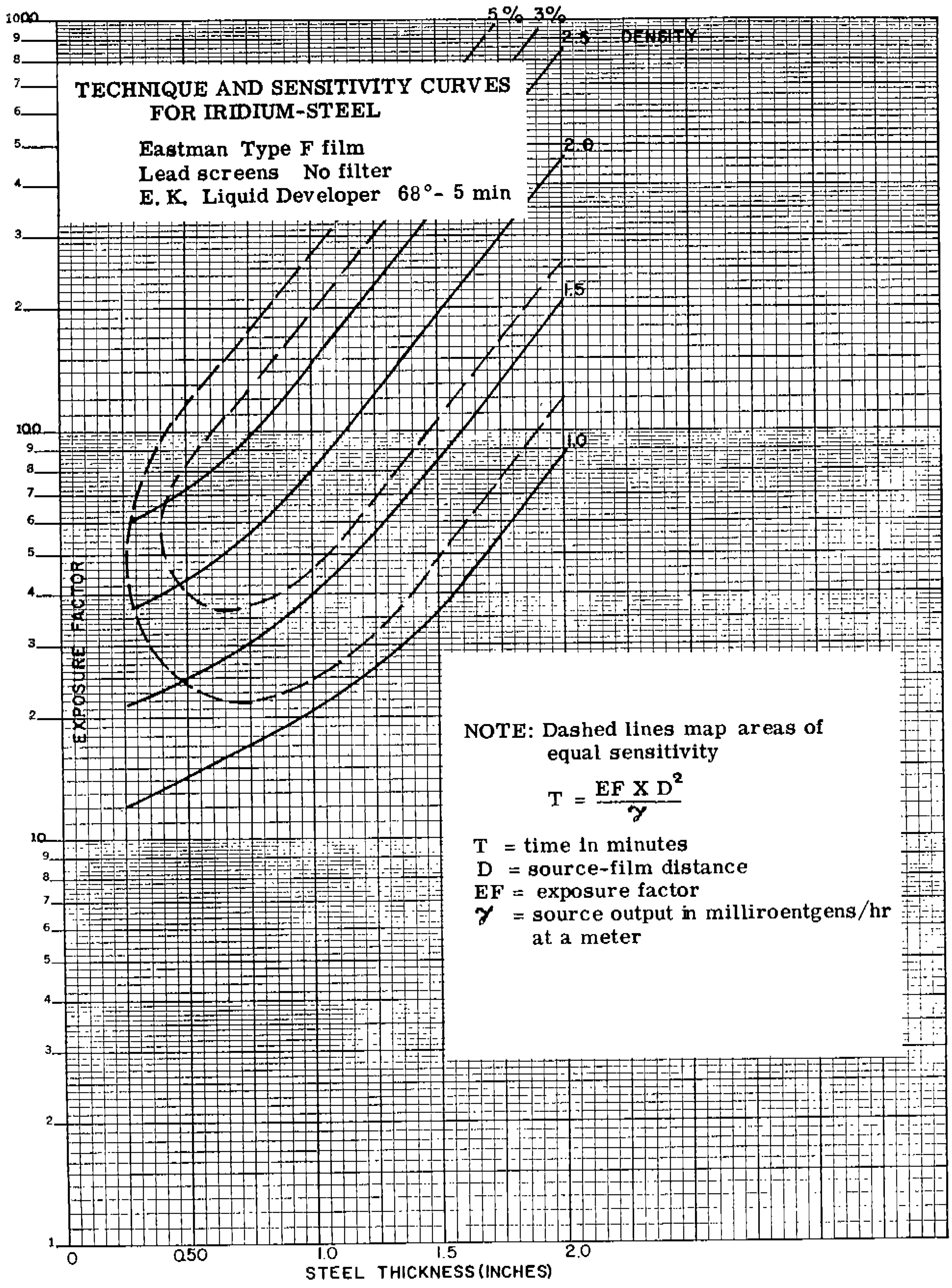
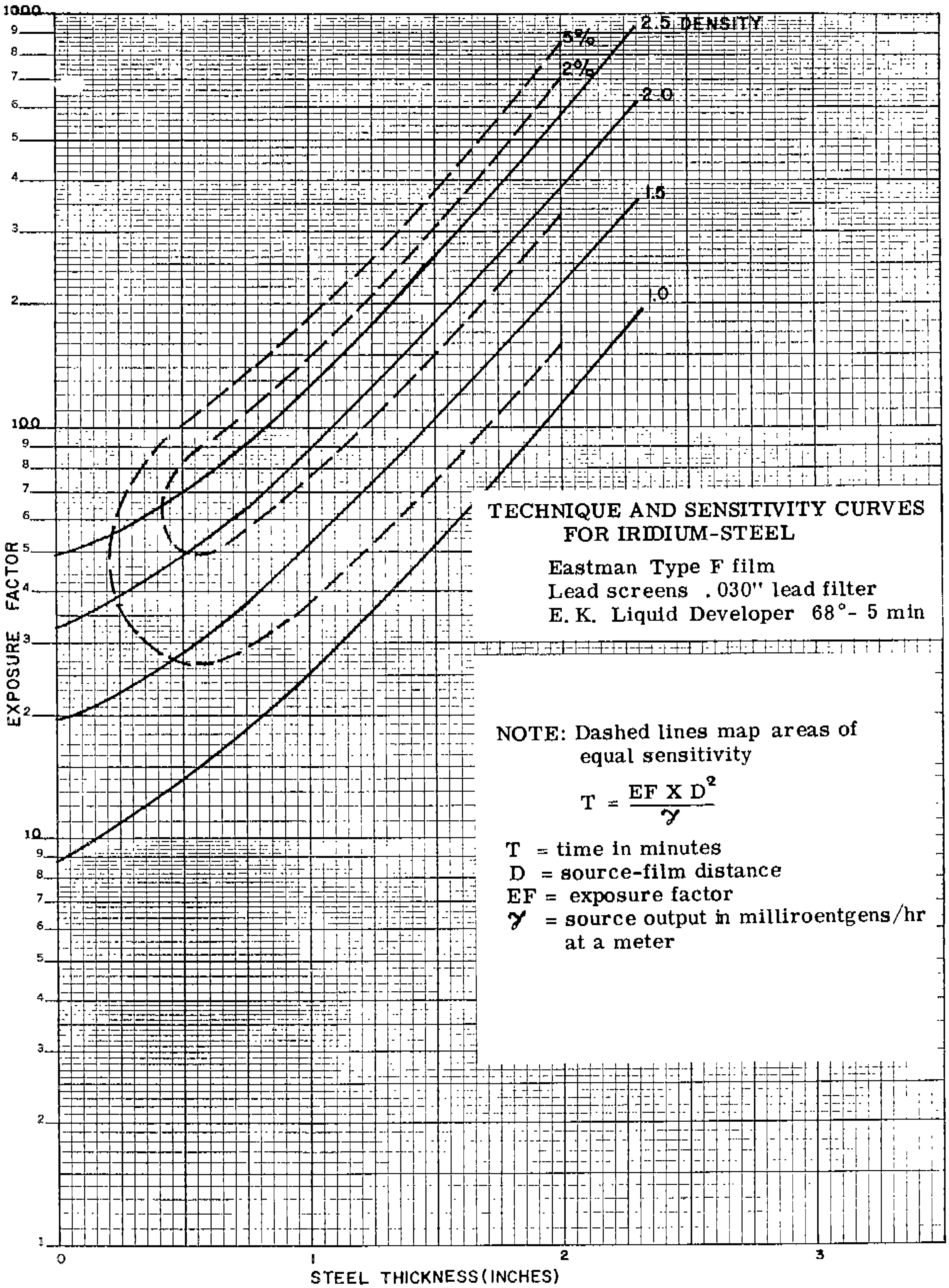

TECHNIQUE AND SENSITIVITY CURVES
FOR IRIDIUM-STEEL
Eastman Type F film
Lead screens No filter
E. K. Liquid Developer 68°- 5 min
5% 3%
2.5 DENSITY
2.0
1.5
1.0
EXPOSURE FACTOR
NOTE: Dashed lines map areas of equal sensitivity
T = EF X D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor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

Chart No. 11



2.5 DENSITY
2.0
1.5
1.0
5%
2%
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
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

Chart No. 12

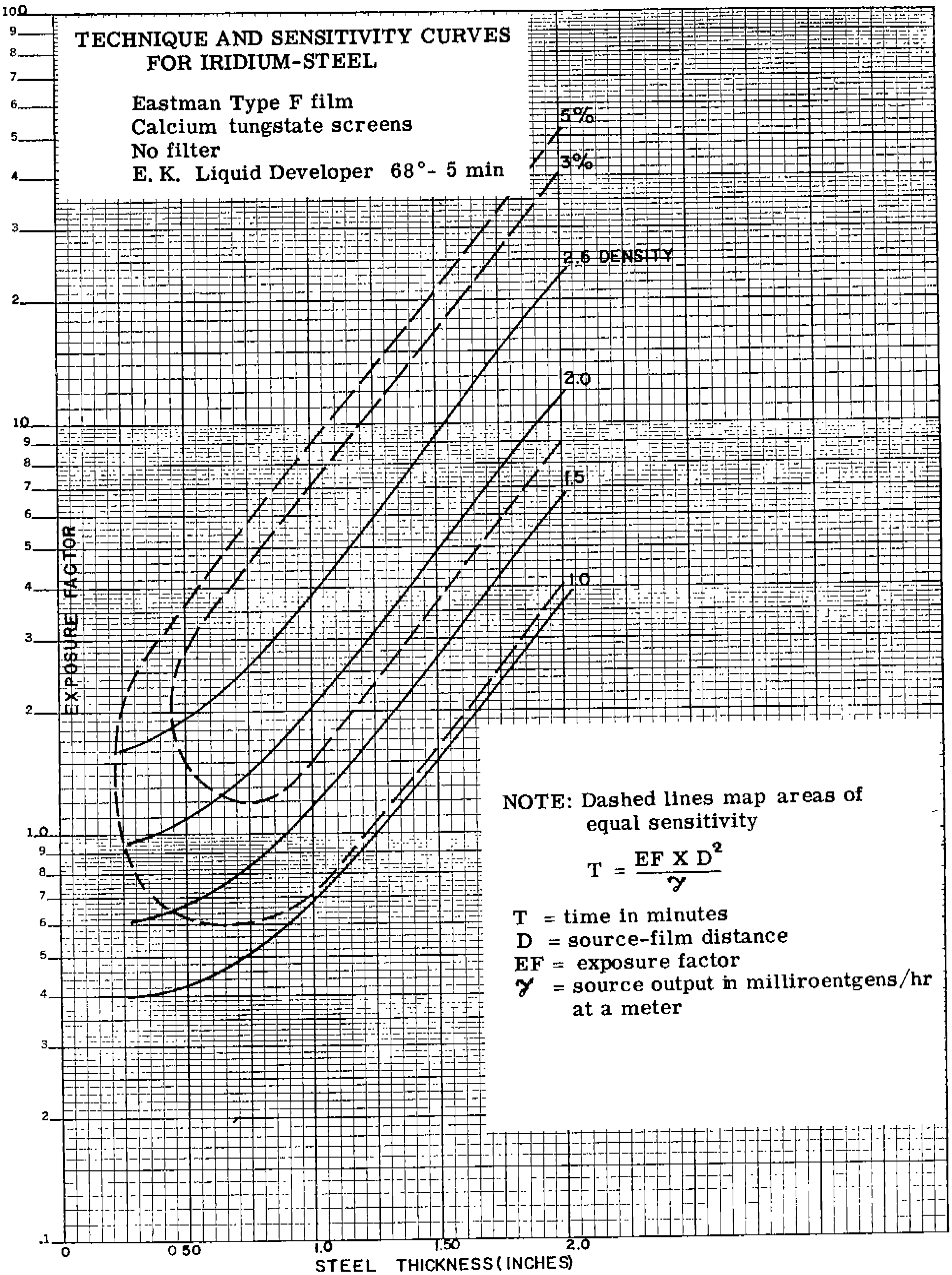

TECHNIQUE AND SENSITIVITY CURVES
FOR IRIDIUM-STEEL
Eastman Type F film
Calcium tungstate screens
No filter
E. K. Liquid Developer 68°- 5 min
5%
3%
2.6 DENSITY
2.0
1.5
1.0
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter
EXPOSURE FACTOR
100
10
1.0
.1
0
0 50
1.0
1.50
2.0
STEEL THICKNESS (INCHES)

Chart No. 13

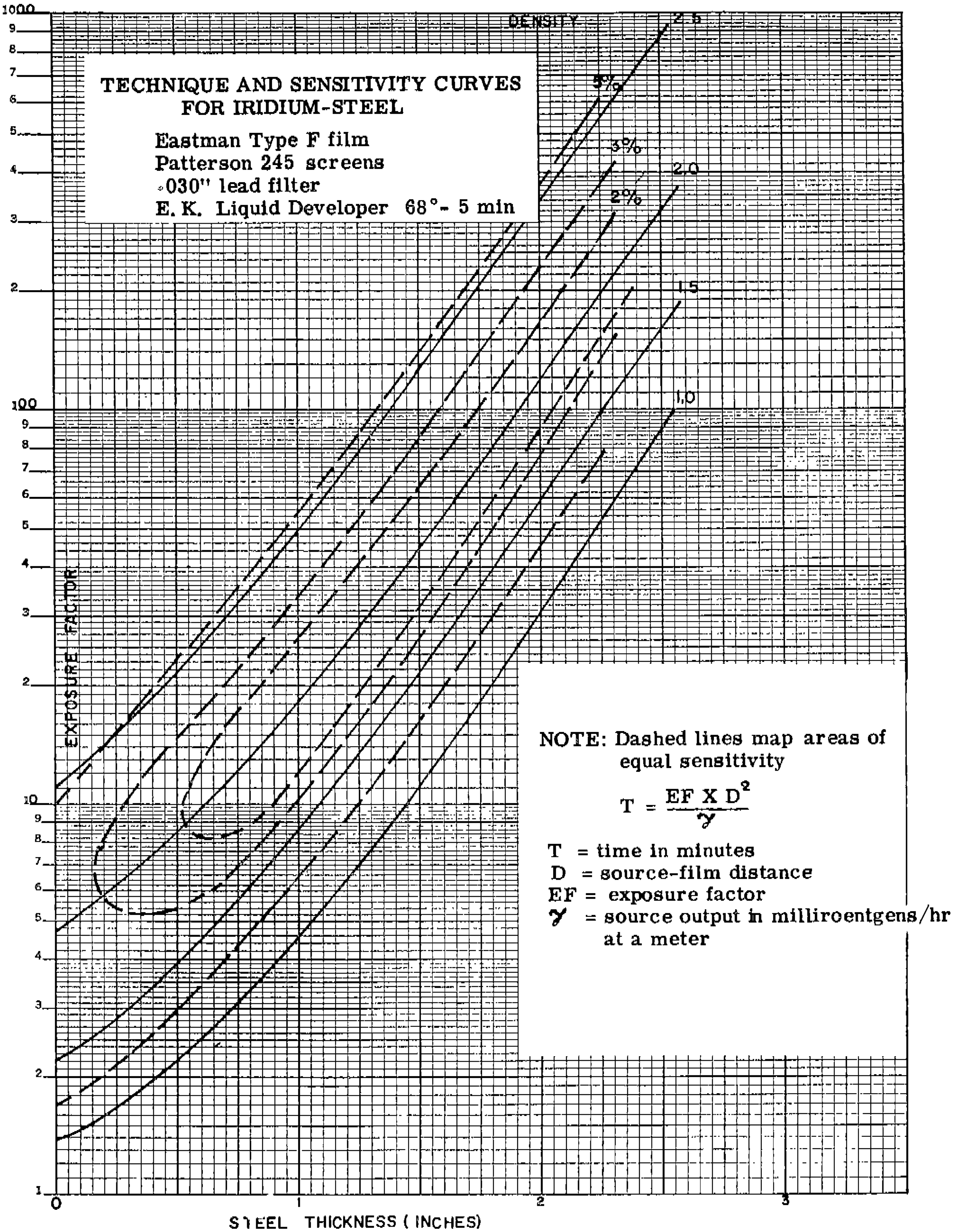
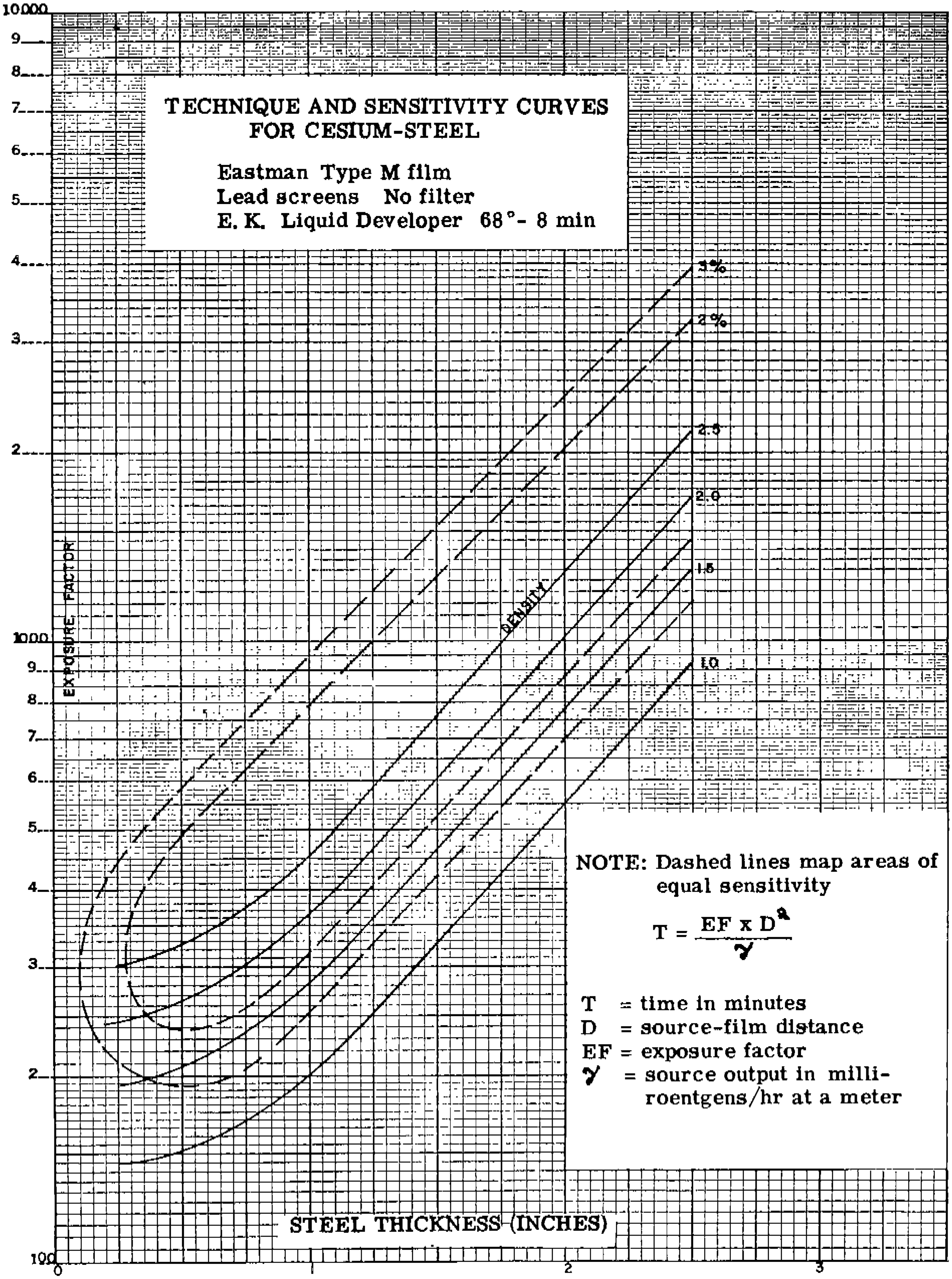

TECHNIQUE AND SENSITIVITY CURVES
FOR IRIDIUM-STEEL
Eastman Type F film
Patterson 245 screens
.030" lead filter
E. K. Liquid Developer 68°- 5 min
DENSITY
2.5
2.0
1.5
1.0
5%
3%
2%
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$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

Chart No. 14



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
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 milli-roentgens/hr at a meter

Chart No. 15

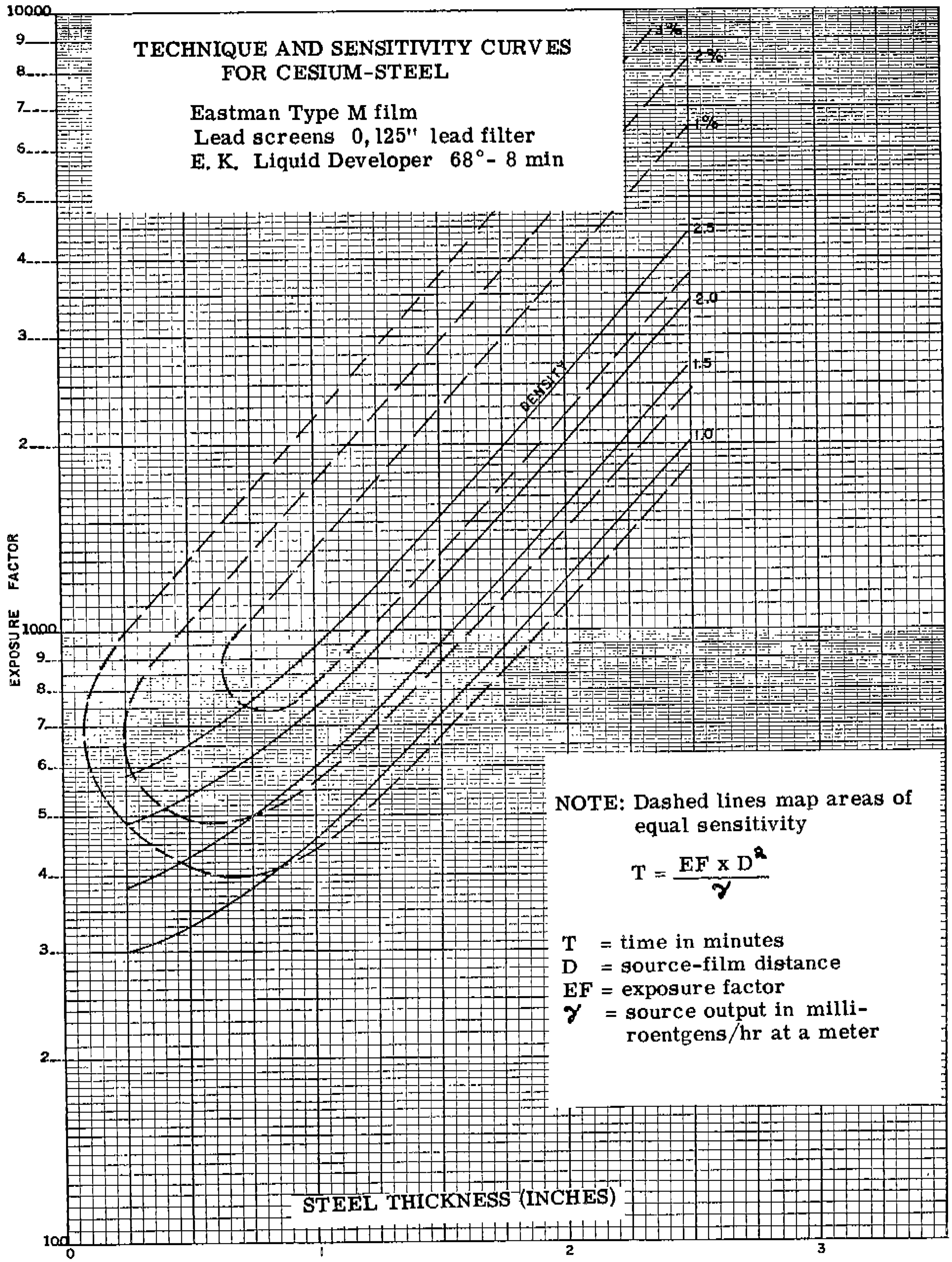

TECHNIQUE AND SENSITIVITY CURVES
FOR CESIUM-STEEL
Eastman Type M film
Lead screens 0,125" lead filter
E. K. Liquid Developer 68°- 8 min
EXPOSURE FACTOR
10000
1000
100
STEEL THICKNESS (INCHES)
0
1
2
3
2%
1%
2.5
2.0
1.5
1.0
DENSITY
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time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

Chart No. 16

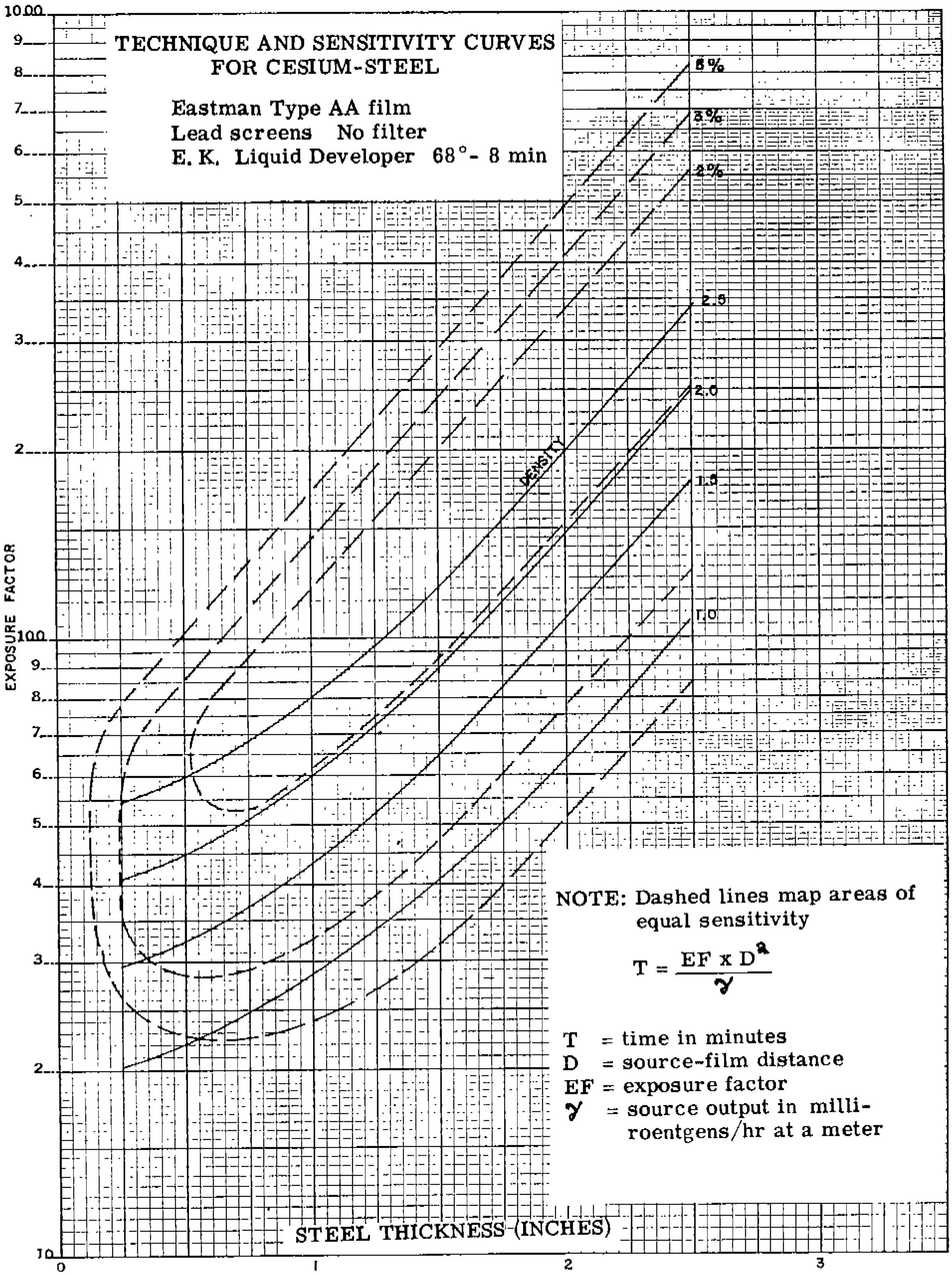

TECHNIQUE AND SENSITIVITY CURVES FOR CESIUM-STEEL
Eastman Type AA film
Lead screens No filter
E. K. Liquid Developer 68° - 8 min
6%
3%
2%
2.5
2.0
1.5
1.0
DENSITY
EXPOSURE FACTOR
1000
100
10
STEEL THICKNESS (INCHES)
0
1
2
3
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 17

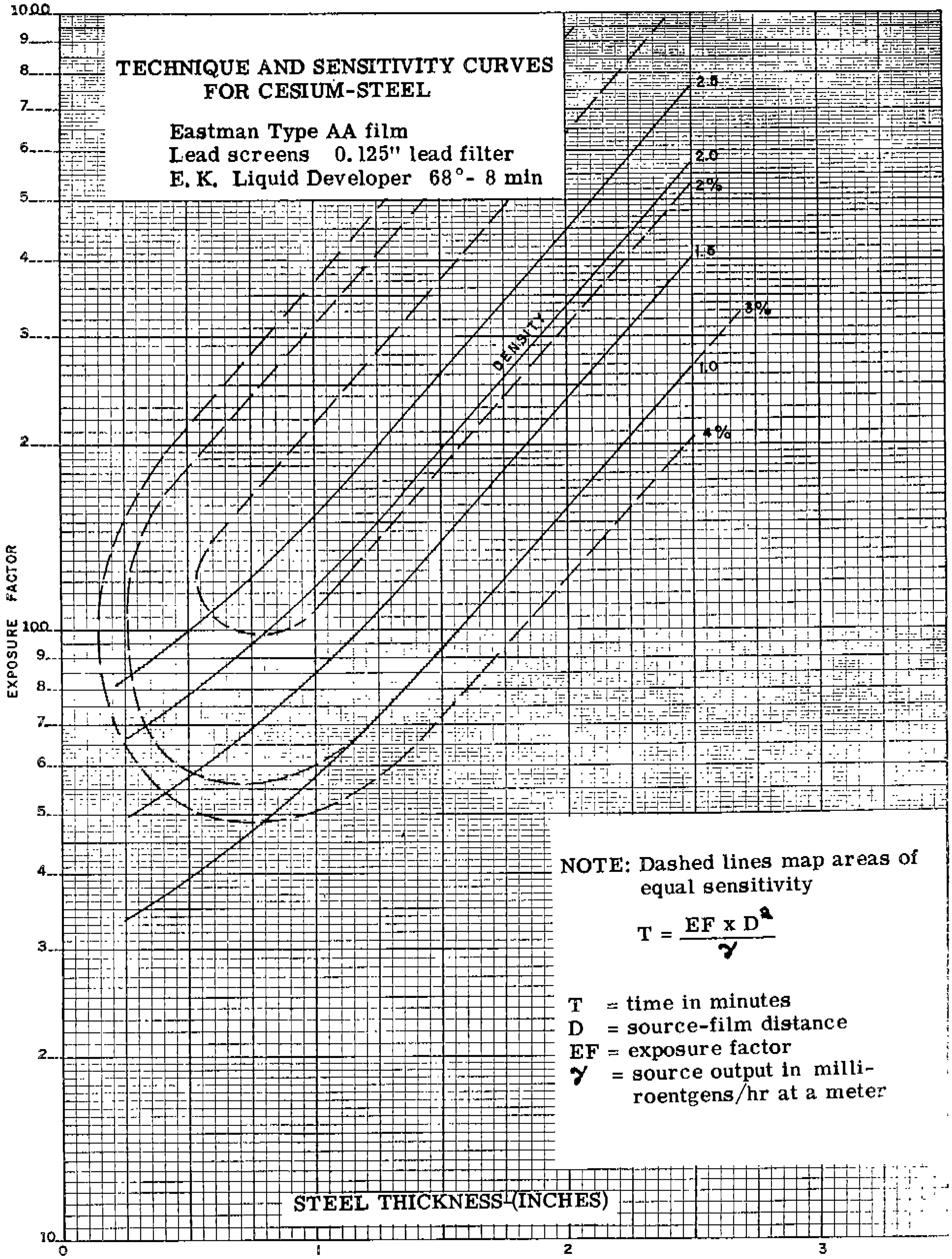
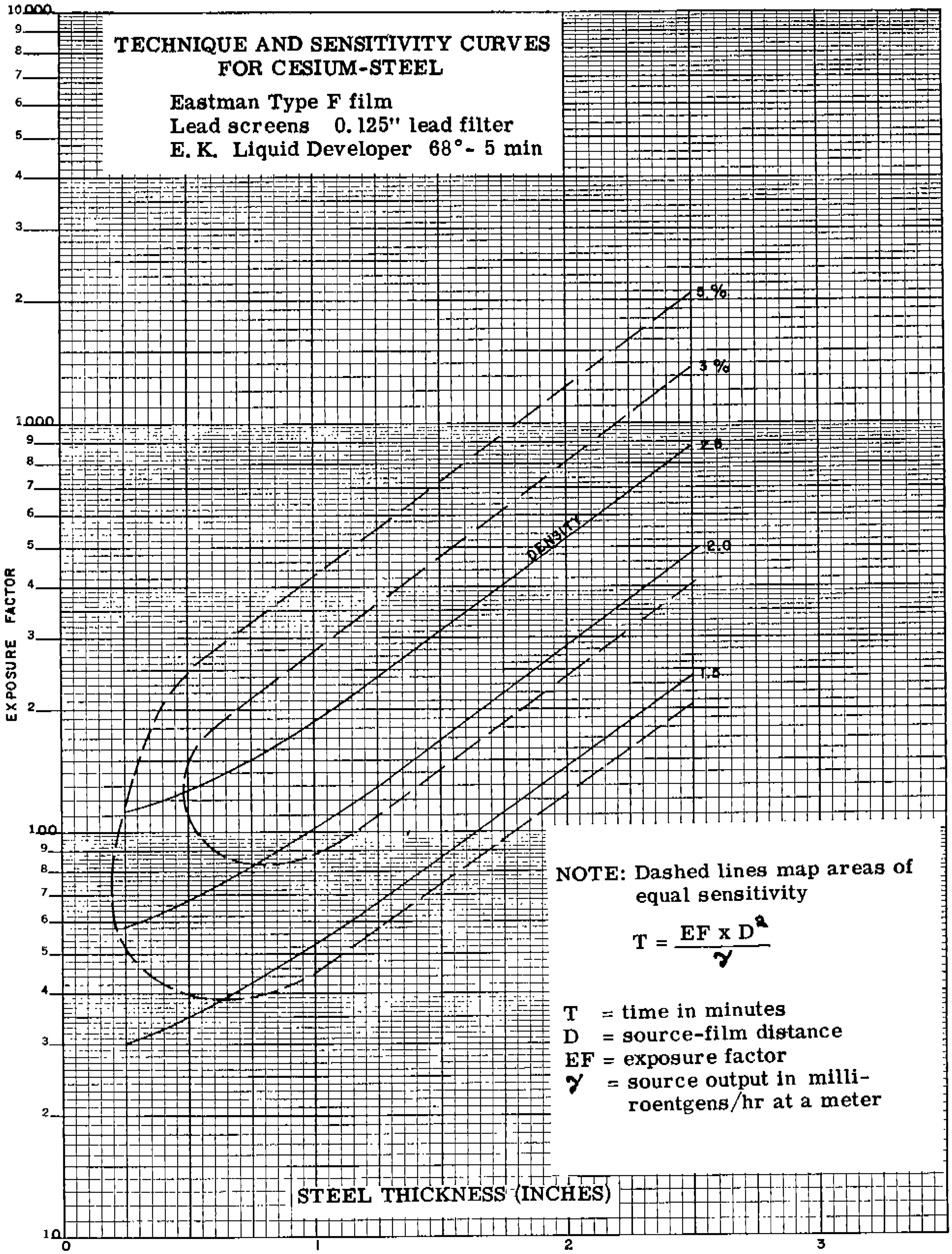

TECHNIQUE AND SENSITIVITY CURVES
FOR CESIUM-STEEL
Eastman Type AA film
Lead screens 0.125" lead filter
E.K. Liquid Developer 68°- 8 min
DENSITY
2.5
2.0
2%
1.5
3%
1.0
4%
EXPOSURE FACTOR
1000
9
8
7
6
5
4
3
2
100
9
8
7
6
5
4
3
2
10
NOTE: Dashed lines map areas of equal sensitivity
T = EF x D² / γ
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milli-roentgens/hr at a meter
STEEL THICKNESS (INCHES)
0
1
2
3

Chart No. 18



TECHNIQUE AND SENSITIVITY CURVES FOR CESIUM-STEEL
Eastman Type F film
Lead screens 0.125" lead filter
E.K. Liquid Developer 68°- 5 min
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
DENSITY
5 %
3 %
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 milliroentgens/hr at a meter

Chart No. 19

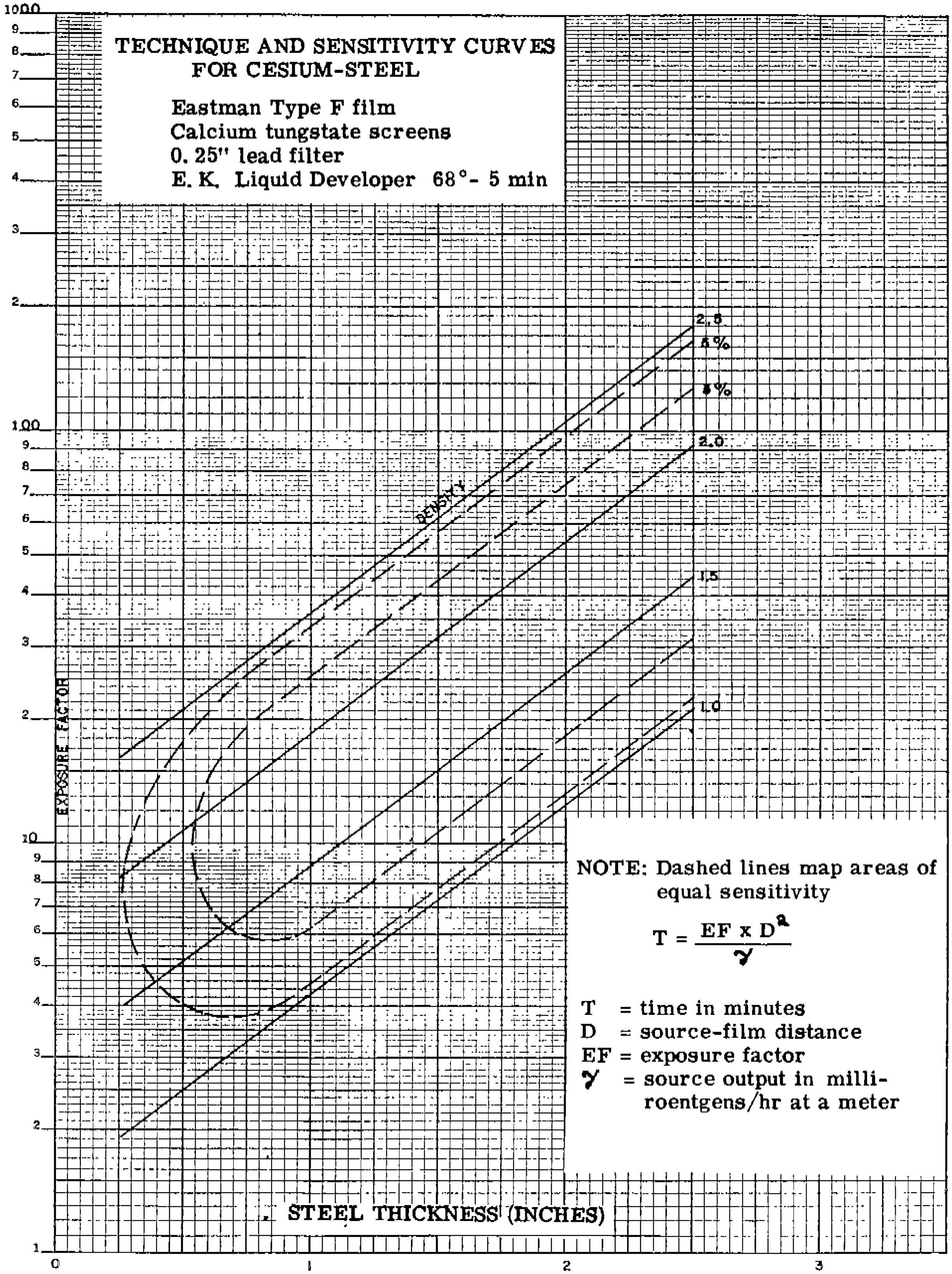
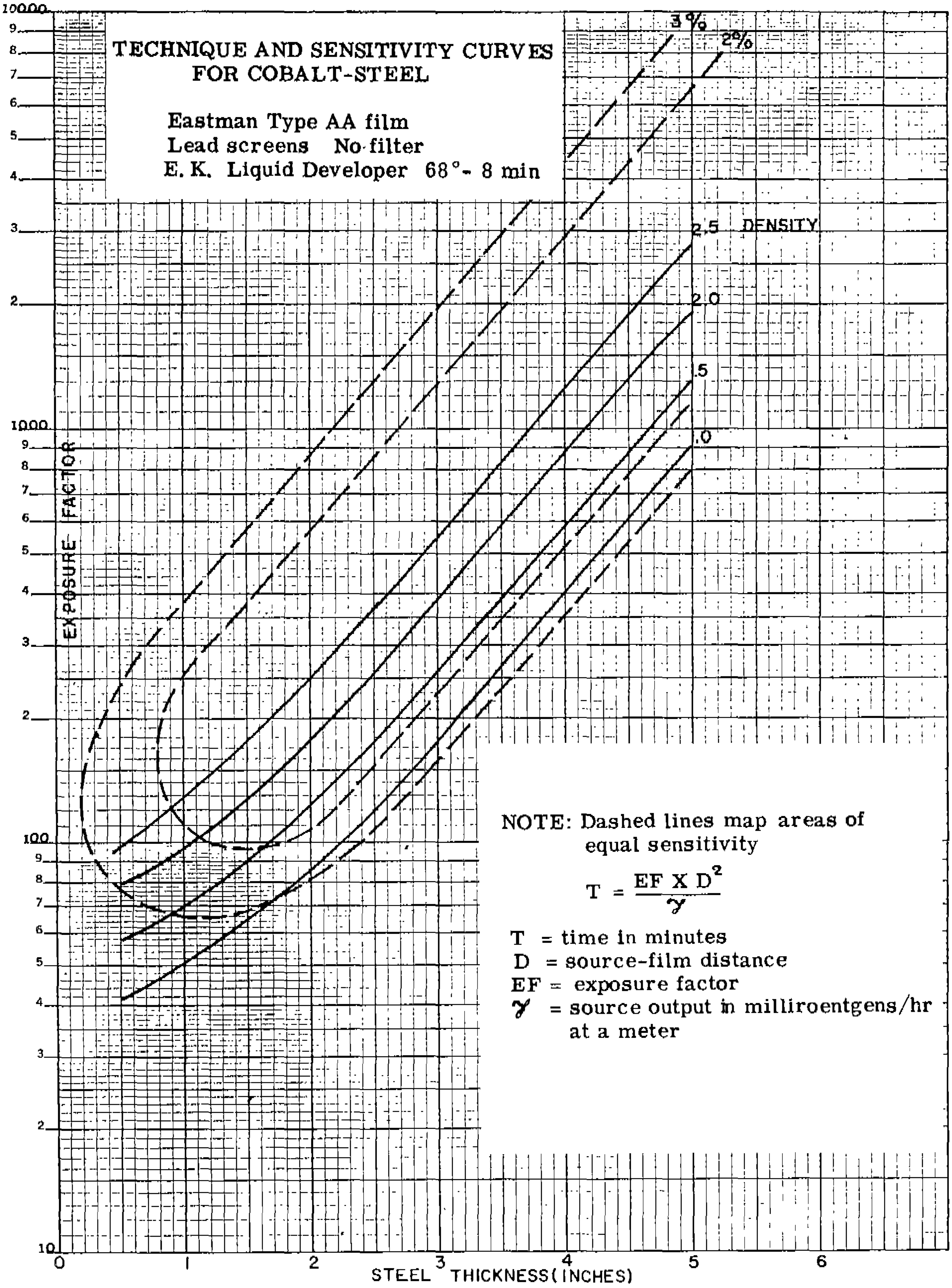

TECHNIQUE AND SENSITIVITY CURVES FOR CESIUM-STEEL
Eastman Type F film
Calcium tungstate screens
0. 25" lead filter
E. K. Liquid Developer 68°- 5 min
DENSITY
2.5
2.0
1.5
1.0
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T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

Chart No. 20



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
.5
.0
EXPOSURE FACTOR
10000
1000
100
10
STEEL THICKNESS (INCHES)
0
1
2
3
4
5
6
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. 21

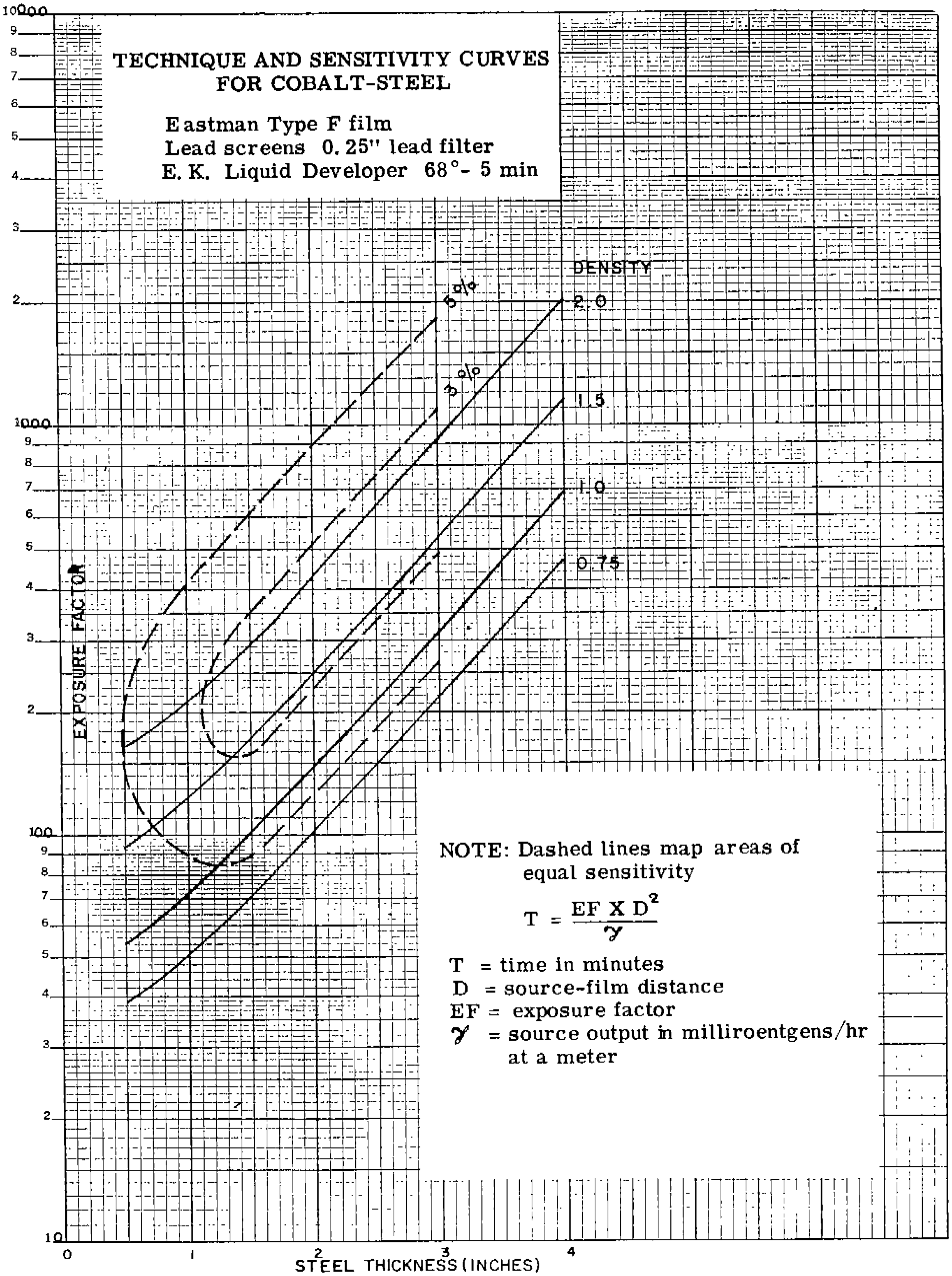

TECHNIQUE AND SENSITIVITY CURVES
FOR COBALT-STEEL
Eastman Type F film
Lead screens 0.25" lead filter
E. K. Liquid Developer 68°- 5 min
DENSITY
2.0
1.5
1.0
0.75
5%
3%
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
0
1
2
3
4
10000
1000
100
10
NOTE: Dashed lines map areas of equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$
T = time in minutes
D = source-film distance
EF = exposure factor
γ = source output in milliroentgens/hr at a meter

Chart No. 22

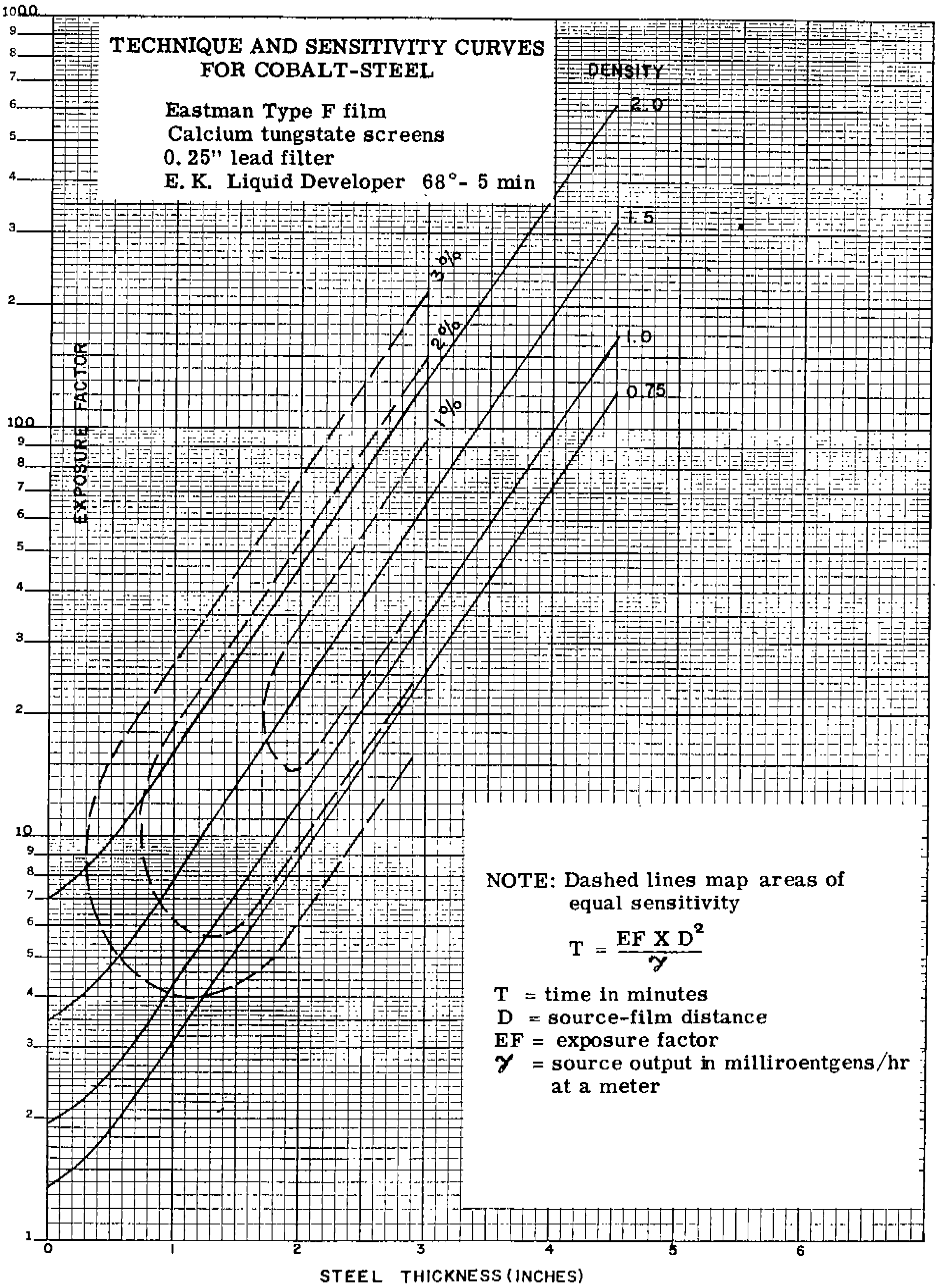

TECHNIQUE AND SENSITIVITY CURVES
FOR COBALT-STEEL
Eastman Type F film
Calcium tungstate screens
0.25" lead filter
E.K. Liquid Developer 68°- 5 min
DENSITY
2.0
1.5
1.0
0.75
3%
2%
1%
EXPOSURE FACTOR
STEEL THICKNESS (INCHES)
NOTE: Dashed lines map areas of
equal sensitivity
$T = \frac{EF \times D^2}{\gamma}$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

Chart No. 23

SHIP STRUCTURE SUBCOMMITTEE

Chairman:

N. Sonenshein, Capt., USN
Head, Hull Design Division
Bureau of Ships

Secretary:

J. D. Crowley, Cdr., USCG
Office of the Engineer-in-Chief
U. S. Coast Guard

Members:

E. C. Vicars, Cdr., USN
Head, Metals Fabrication Branch
Bureau of Ships

John Vasta
Chief, Hull Scientific Section
Bureau of Ships

R. D. Karl, Cdr., USN
Director of the Engineering Division
Maintenance and Repair, M.S.T.S.

Hubert Kempel
Head, Technical Branch
Military Sea Transportation Service

J. B. Robertson, Jr.
Deputy Technical Assistant to Chief
Merchant Marine Technical Division, USCG

V. L. Russo
Deputy Chief, Office of Ship Construction
Maritime Administration

W. G. Frederick
Naval Architect (Structural)
Maritime Administration

D. B. Bannerman, Jr.
Chief Surveyor - Hull
American Bureau of Shipping

G. W. Place
Principal Surveyor, Metallurgy - Research
American Bureau of Shipping

J. J. Harwood
Head, Metallurgical Branch
Office of Naval Research