EVALUATION OF GAMMAGRAPHY FOR DIFFERENT MATERIALS

by
Sinan Büyükyüksel
B.S. in Mechanical Engineering,
Yıldız University, 1980

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EVALUATION OF GAMMAGRAPHY FOR DIFFERENT MATERIALS

APPROVED BY

Doç. Dr. A. Nezihi BİLGE (Thesis Supervisor) . . . . . .

Prof. Dr. Turan B. ENGİNOL . . . . . .

Doç. Dr. Vural ALTIN . . . . . .

Doç. Dr. Salih DİNÇER . . . . . .

DATE OF APPROVAL

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ABSTRACT

Gammagraphy which is a part of radiography, is one of the important and effective methods in nondestructive testing and determination of exposure time in gammagraphy has a special importance from the point of view of radiographic results. The aim of this study is to evaluate the methods of exposure time determination (ETD) then, after choosing the most reliable method, to construct ETD tables for workers in this field.

There are several methods used in determination of exposure time in gammagraphy. In this study "exposure chart" method which is an experimental method and a theoretical approach is used. The theoretical method is modified by using build up factors and improved as an "alternative" method. The reason for the choice of these methods is that they are very appropriate for computer analysis so that a realistic comparison of the methods could be done.

The study can be divided into two main parts. In the first step, all ETD methods were computerized for several gamma sources, films, film densities, and materials and the results were compared. Then, in the next step, which is the experimental part of the study, some radiographs were taken with all the methods by using a 30 Curies Cobalt-60 source and the method giving the best result was determined.

The results obtained from the computer analysis and experiments showed that the alternative method has given the best radiographs among the other ETD methods.

ÖZET

Bu çalışmada tahribatsız muayene usulleri içinde önemli bir yeri bulunan gamagrafide ekspoşur sürelerini belirleyen metodlar (ETD methods) incelenmiştir.

Bütün ETD metodları bilgisayara göre düzenlenerek çeşitli gama kaynakları, filmler, film yoğunlukları ve malzemeler için incelenmiş ve mukayese edilmişlerdir.

Çalışmanın ikinci kısmını teşkil eden laboratuvar çalışmaları ÇNAEM'in endüstriye uygulama laboratuvarlarında gerçekleştirilmiş ve 30 kürilik bir Kobalt-60 kaynağı kullanılarak en iyi ETD metodu tesbit edilmeye çalışılmıştır.

Deneysel sonuçlar bilgisayar verileri ile mukayese edilmiş ve geliştirilen "Alternative Method"un en iyi radyografik sonuçları verdiği tesbit edilmiştir.

"Alternative Method"a göre geliştirilen ekspoşur tabloları ve cetvelleri bu alanda çalışanların yararına sunulmuştur.

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B	Build-up Factor
D	Source-to-film Distance (cm)
D	Film Density
F	Film Factors
h	Exposure Time (min.)
I	Radiation Intensity (dis / sec)
J	Light Intensity
Q	Exposure (Curie)
S	Source Activity (dis / sec)
t	Time (min)
x	Specimen Density Thickness (gr / cm^2)
x	Specimen Thickness (cm)
β	Beta Particle
γ	Gamma Photon
μ'	Effective Absorption Coefficient (cm^2 / gr)
μ	Linear Absorption Coefficient (cm^{-1})
μ'	Mass Absorption Coefficient (cm^2 / gr)

I. GENERAL ASPECTS OF GAMMAGRAPHY

1.1. Introduction

Today, nondestructive methods for examining the raw, semi-finished or finished products are spread all over the industry and are well known inspection techniques. In general there are several nondestructive testing methods namely visual, acoustic (sonic and ultrasonic), pressure and leak, magnetic, penetrant, electrical and electrostatic, thermal, electromagnetic induction, radiography and miscellaneous. Gammagraphy is one of the radiographic methods used in nondestructive testing. By using this technique, inhomogenities or defects in the materials can be detected without destroying the material. Radiography uses x-ray or nuclear radiations such as gamma rays, neutrons, alpha or beta particles to obtain pictures of the interior of opaque materials. Radiography, unless otherwise specified, refers to the usage of x-rays or gamma rays which are penetrating types of radiation.

Radioactivity which is the characteristic of certain nuclides to emit spontaneously alpha, beta and gamma rays has been known since the first decade of this century. During the 38 years which followed its discovery, radioactivity did not exist outside the rare materials found in nature. This meant that practical applications were not only exceedingly difficult but were also very costly.

In 1934, Joliot and Curie[8] succeeded in producing an artificial radioactive element. During the following years more and more new artificial radioactive elements were discovered, but the quantities produced were so small that they could not be considered for any immediate application. They were utilized only for laboratory experiments, in particular in biology and medicine.

In 1947, when radioactive isotopes were produced in very large quantities[8] in course of atomic fission operations in nuclear reactors or were prepared by means of these machines they became available for use in radioactive isotope applications industry at reasonable costs because they were after all by-products of nuclear processes.

1.2. Radioactivity and Gamma Radiation

1.2.1. Radioactivity

Radioactivity means that the radioactive isotope continuously undergoes a spontaneous disintegration. The process usually involves the emission of one or more of a number of smaller particles from the "parent" nucleus, after which the latter is changed into another, or "daughter", nucleus. The parent nucleus is said to decay into the daughter nucleus which may not in itself be stable, and several stages of successive decay may then take place before a stable isotope is formed.

Naturally occuring radioisotopes emit one or more of the following three types of particles or radiations: alpha particles, beta particles and gamma radiation. The artificially produced isotopes in addition to above, emit or undergo the following particles or reactions respectively, positron or beta$^+$ particles, orbital electron absorption, called K capture, and neutrons.

Gamma ray intensity: Measurement of the gamma ray intensity is in roentgens per hour at one meter which is a measure of radiation emission over a given period of time at a fixed distance. The activity (amount of radioactive material) of a gamma ray source determines the intensity of its radiation. The activity of artificial radioisotope sources is determined by the effectiveness of the neutron bombardment that created the isotopes. The measure of activity is the curie ($3.7\ 10^{10}$

disintegrations per second).

Specific activity: Specific activity is defined as the degree of concentration of radioactive material within a source. It is usually expressed in terms of curies per gram or curies per cubic centimeter. Two isotope sources of the same material with the same activity (curies) having different specific activities will have different dimensions. The source with the greater specific activity will be the smaller of the two. For radiographic purposes, specific activity is an important measure of radioisotopes, since the smaller the radioactive source the greater the sharpness of the resultant film image.

Half-life: The length of time required for the activity of a radioisotope to decay (disintegrate) to one-half of its initial amount is termed "half-life". The half-life of a radioisotope is a basic characteristic, and is dependent upon the particular isotope of a given element. In radiography, the half-life of a gamma ray source is used as a measure of activity in relation to time, and dated decay curves similar to that shown in Fig. 1.1, are supplied with radioisotopes upon procurement.

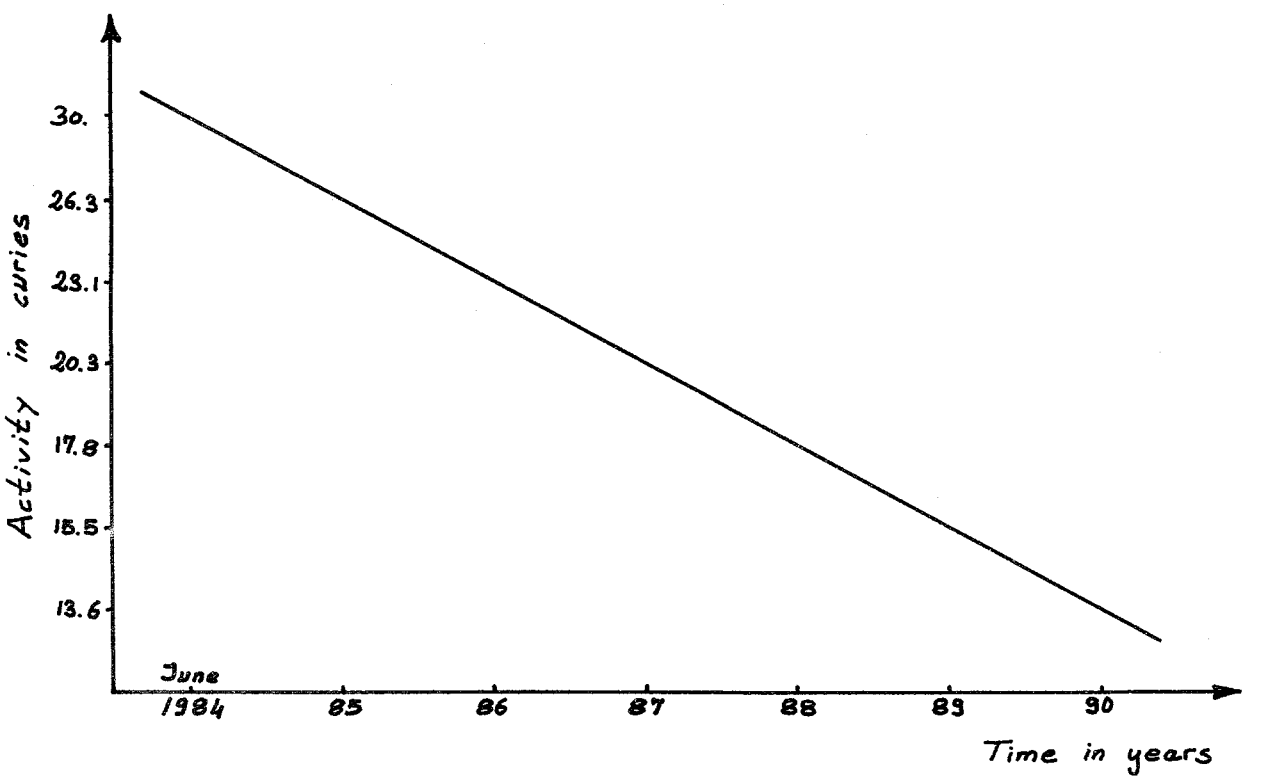


FIG. 1.1 Dated decay curve of a Co-60 source.

1.2.2. Electromagnetic Radiation

Gamma rays are electromagnetic radiation like x-rays and comprise the high energy, short wavelength portion of the electromagnetic wave spectrum, as shown in Fig. 1.2. Throughout the spectrum, x- and gamma rays have the same characteristics, and x- and gamma rays of the same wavelength have identical properties.

Radiographic nondestructive testing is based on the following characteristics of the electromagnetic nature of the gamma rays.

1- Their energy is inversely proportional to their wavelength.
2- They have no electrical charge and no mass.
3- They travel in straight lines at the velocity of light.
4- They can penetrate matter, the depth of penetration being dependent upon the energy of the rays.

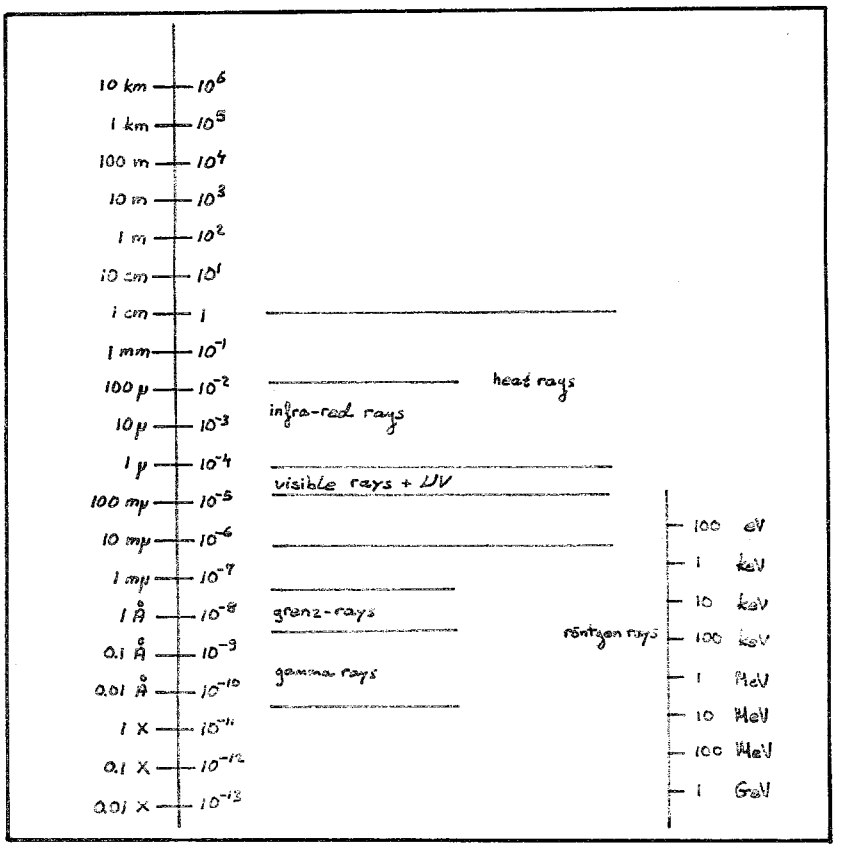


FIG. 1.2 The electromagnetic spectrum.

5- They are absorbed by matter, the percentage of absorption being directly proportional to matter density and thickness, and indirectly proportional to energy.
6- They are scattered by matter, the amount of scatter being directly proportional to material density, and indirectly proportional to energy.
7- They can ionize matter.
8- They can expose film by ionization.
9- They can produce fluorescence in certain materials.
10- They are invisible and incapable of detection by any of the senses.

1.2.3. Gamma Ray Interaction with Matter

Gamma ray interaction with matter is the main principle of gammagraphy. When a beam of gamma radiation falls on an object, some of it is transmitted through, some absorbed and some scattered in other directions. There are three processes which take place as gamma rays pass through matter, namely, the photoelectric effect, pair production, and Compton scattering

In the photoelectric effect, the photon is absorbed by an atom and one of the bound electrons in the atom is ejected. Electrons in the K and L shells account for most of the absorption by this prosses. The probability of this process occurring increases with increasing atomic number and decreases as the photon energy increases.

In pair production a photon with an energy greater than 1.02 MeV is absorbed in the atoms and produces a pair of electrons. One electron is positively charged and the other negatively charged. The probability of this absorption process increases with the photon energy and with atomic number.

In Compton scattering the photon is deflected by an atomic electron. Only part of the energy of the photon is lost, and the photon continues with lower energy in a direction different from its initial direction of travel. The atomic

electron recoils out of the atom. The probability of this scattering process decreases with increasing photon energy and is proportional to the number of atomic electrons.

1.2.4. Gamma Ray Sources

Gamma rays are produced by the nuclei of isotopes which are undergoing disintegration because of their basic instability. Isotopes are varieties of the same chemical element having different atomic weights. A parent element and its isotopes all have an identical number of protons in their nuclei but a different number of neutrons. Among the known elements, there are more than 800 isotopes of which more than 500 are radioactive. The wavelength and intensity of gamma waves are determined by the source isotope characteristics, and can not be controlled or changed.

Natural isotope sources: Every element whose atomic number is greater than 82 has a nucleus that will probably disintegrate because of its inherent instability. Radium, the best known, and most used, natural radioactive source is typical of all radioactive substances. Radium and its daughter products release energy in the form of:

1- Gamma rays: Short wavelength electromagnetic radiation of nuclear origin.
2- Alpha particles: Helium nuclei, consisting of two protons and two neutrons, with a double positive charge.
3- Beta particles: Negatively charged particles having mass and charge equal in magnitude to those of the electron.

The penetrating power of alpha and beta particles is relatively negligible, it is the gamma rays that are of use to the radiographer.

Artificial sources: There are two sources of man-made radioactive isotopes (radioisotopes). One of them is atomic reactor operation, involving the fission of Uranium-235 which results in the production of many different isotopes usable as radiation sources. Cesium-137, one of the radioisotopes used in radio-

graphy, is obtained as a by-product of nuclear fission.

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{137}_{56}Ba + ^{97}_{36}Kr + 2\,^{1}_{0}n + 200\ Mev \qquad \text{(Eq. 1.1)}$$

$$^{137}_{56}Ba \longrightarrow ^{137}_{55}Cs + ^{+}\beta \qquad \text{(Eq. 1.2)}$$

The second, and most common, means of creating radioisotopes is by bombarding certain elements with neutrons. The nuclei of the bombarded element are changed, usually neutron capture and thereby may become unstable or radioactive. Commonly used radioisotopes obtained by neutron bombardment are, Cobalt-60, Iridium-192 and Thulium-170. The creation of Cobalt-60 by neutron bombardment is shown below as an example:

$$^{1}_{0}n + ^{59}_{27}Co \longrightarrow ^{60}_{27}Co + \gamma \qquad \text{(Eq. 1.3)}$$

The numerical designator of each of these isotopes denotes its mass number and distinguishes it from the parent isotope, and other isotopes of the same element. Artificially produced isotopes emit gamma rays, alpha particles, and beta particles in exactly the same manner that natural isotopes do[1].

1.2.5. Radioisotope Sources Used in Radiography

The principle of gammagraphy is that, the gamma radiation is produced by the spontaneous disintegration of atomic nuclei in the radioactive source and gamma rays possess the capability of penetrating materials, even those that are opaque to light. In passing through matter, some of these rays are absorbed. The amount of absorption at any point is dependent upon the thickness and density of the matter at that point: Therefore, the intensity of the rays emerging from the matter varies. When this variation is

detected and recorded, usually on a film, a means of inspecting the insides material becomes available.

Despite the existence of many natural and artificial radioisotopes emitting gamma radiations, only a few of them are useful for gammagraphy because they should have appropriate half-life, energy, and price. For the sake of safety it is also preferable to use solid state radioisotopes in gammagraphy. Consequently the most commonly used radioisotopes, are Cobalt-60, Cesium-137, Iridium-192, and Thulium-170.

1- Cobalt-60: Cobalt 60 is an artificial isotope created by neutron bombardment of cobalt, having a half-life of 5.3 years. Cobalt-60 primary gamma ray emission consists of 1.33 and 1.17 Mev rays similar in energy content to the output of a 2 Mev x-ray machine. The radioisotope is supplied in the form of a capsuled pellet and may be obtained in different sizes. It is used for radiography of steel, copper, brass and other medium weight metals of thicknesses ranging from 40mm to 200mm. Because of its penetrating radioation, its use requires thick shielding, with resultant weight and handling difficulty.

2- Iridium-192: Iridium-192, another artificial isotope produced by neutron bombardment, has a half-life of approximately 75 days. It has high specific activity and emits gamma rays in the range of 0.296 to 0.612 Mev, comparable in penetrating power to those of a 600-kvp x-ray machine. Industrially, it is used for radiography of steel and similar metals of thicknesses between 12 and 100mm. Its relatively low energy radiation and its high specific activity combine to make it an easily shielded, strong radiation source of small physical size (focal spot). The radioisotope is obtainable in the form of a capsuled pelled.

3- Thulium-170: Thulium-170 obtained by neutron bombardment of thulium has a half-life of approximately 130 days. The disintegration of the isotope produces 84-kev and 52-kev gamma rays, soft rays similar to the radiation

of x-ray equipment operating in the 50- to 100 kvp range. It is the best isotope known for radiography of thin metals since it is capable of producing good radiographs of steel specimens less than 40mm thick. One of the major advantages of the use of Thulium-170 is its soft wave radiation, which permits its containment in small equipment units of extreme portability, since only a small amount of shielding is required. Because the pure metal is difficult to obtain, the isotope is usually supplied in capsules containing the oxide Tm_2O_3 in powder form.

4- Cesium-137: Cesium-137, a by-product of the fission process, has a half-life of 30 years. It emits gamma rays of 0.66 Mev, equivalent in energy to the radiation of a one Mev x-ray machine. It is used in radiography of steel of thicknesses between 20 and 100mm. It is superior to other isotopes of similar capability only in its slow rate of decay. Cesium-137 is usually handled in the form of the chloride CsCl, a soluble powder requiring special safety precautions. The USAEC recommends double encapsulation in containers constructed of silver-brazed stainless steel[1].

Isotope	Cobalt-60	Cesium-137	Iridium-192	Thulium-170
Half life	5.3 yr.	30 yr.	75 days	130 days
Chemical form	Co	CsCl	Ir	Tm_2C_3
Gammas Mev	1.33,1.17	0.66	0.296-0.612	0.084,0.052
Steel thickness range*	40-200mm	20-100mm	12-100mm	> 40mm

Table 1.1 Isotope characteristics.

*Permissible thickness range for isotope inspection (two percent sensitivity)

Advantages and disadvantages of gamma sources: Radioisotope sources that emit gamma-rays have some advantages and disadvantages over x-ray machines in radiography. These are:
as advantages:

1- Radioisotope sources are relatively cheep.
2- They can be made quite small.
3- They give a very constant output independent of changes in ambient conditions.
4- They are portable.
5- The maintenance cost is negligible.

as disadvantages:

1- They can not be "turned off".
2- The energy of the radioisotope can not be varied after the original selection is made.
3- There are few inexpensive low-energy sources available with long half-lives.

1.3. Basic Factors Affecting Exposure and Radiographic Quality

1.3.1. Geometric Exposure Principles

Since a radiograph is a shadow picture, the image produced is affected by the relative positions of the specimen and film and by the size of the focal spot of the gamma source. The ideal condition would be a point source of radiation. Since the focal spot has definite size there will be a small amount of blurring or unsharpness around the edges of the specimen, as shown in Fig. 1.3. From the similar triangles in Fig. 1.3,

$$\frac{FF'}{d} = \frac{U}{t} \qquad \text{(Eq. 1.4)}$$

$$U = \frac{(FF')t}{d} \qquad \text{(Eq. 1.5)}$$

where FF' = size of focal spot
d = source-to-specimen distance
U = unsharpness
t = specimen-to-film distance

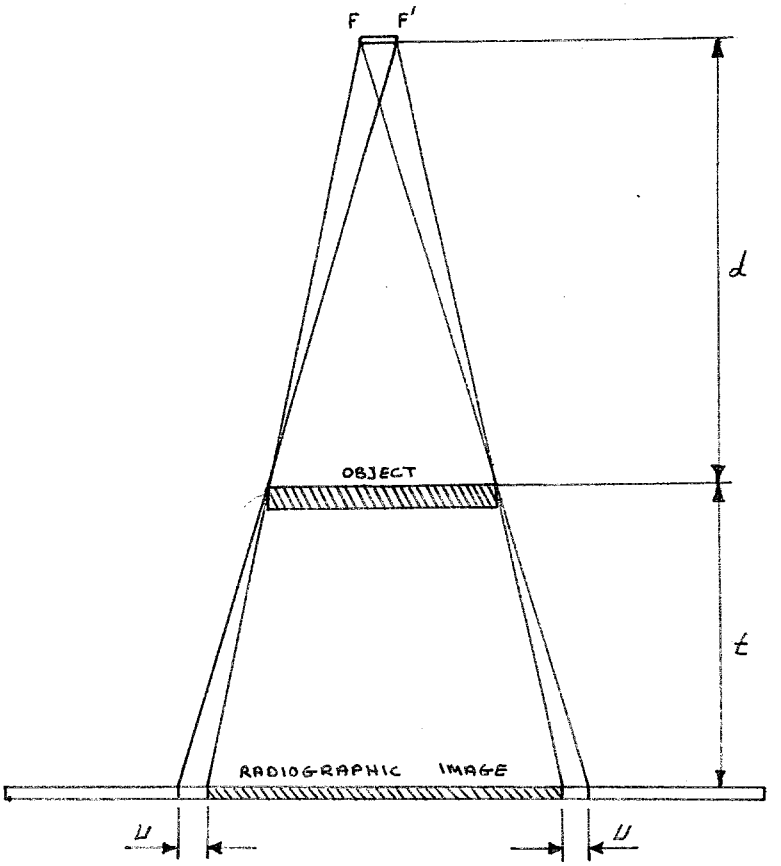


FIG. 1.3 Geometrical unsharpness

As can be seen from this equation, the smaller the focal spot, the less the unsharpness. Equation 1.5 also shows that the unsharpness is inversely proportional to the source-to-specimen distance. It is advisable to use the longest source-to-film distance possible consistent with a reasonable exposure time, the exposure time being directly proportional to the square of the distance. The unsharpness varies in direct proportion to specimen-to-film distance. The film should be as close as possible to the specimen. The greater the d/t ratio, the better the definition on the radiograph. Definition or detail is the characteristic of

a radiograph which describes the sharpness of the image. Deviation from the true shape of the specimen in the shadow picture is called "distortion".

1.3.2. Films and Modifying Equipment

Films: Radiographic film consists of a thin, transparent plastic sheet coated on one or both sides with an emulsion of gelatin, approximately 0.025mm thick, containing very fine grains of silver bromide. When exposed to x-or gamma rays, silver bromide crystals undergo a reaction that makes them more susceptible to the chemical process (developing) that converts them to black metallic silver. In short, exposure to radiation creates a latent image on the film, and chemical processing makes the image visible. The usefulness of any radiograph is measured by its impact on the human eye. When the radiographer interprets a radiograph he is seeing the details of the specimen image in terms of the amount of light passing through the processed film. Areas of high density (areas exposed to relatively large amounts of radiation) will appear dark gray, areas of light density (areas exposed to less radiation) will appear light gray, Fig. 1.4. The density difference between any two film areas is known as contrast. The sharpness of the film image is known as definition. Successful interpretation of any radiograph relies upon contrast and definition detectable by the eye.

Subject contrast is the ratio of radiation intensities passing through any two selected portions of a specimen. Homogeneous specimens of little thickness variation have low subject contrast. Those of large thickness variation usually have high subject contrast. Subject contrast is determined by specimen density and thickness, and the radiation energy applied. Normally, as the energy of the applied radiation is lowered, the subject contrast is increased. High subject contrast is desirable except when detail is lost in the extremely dark and light areas of the radiograph.

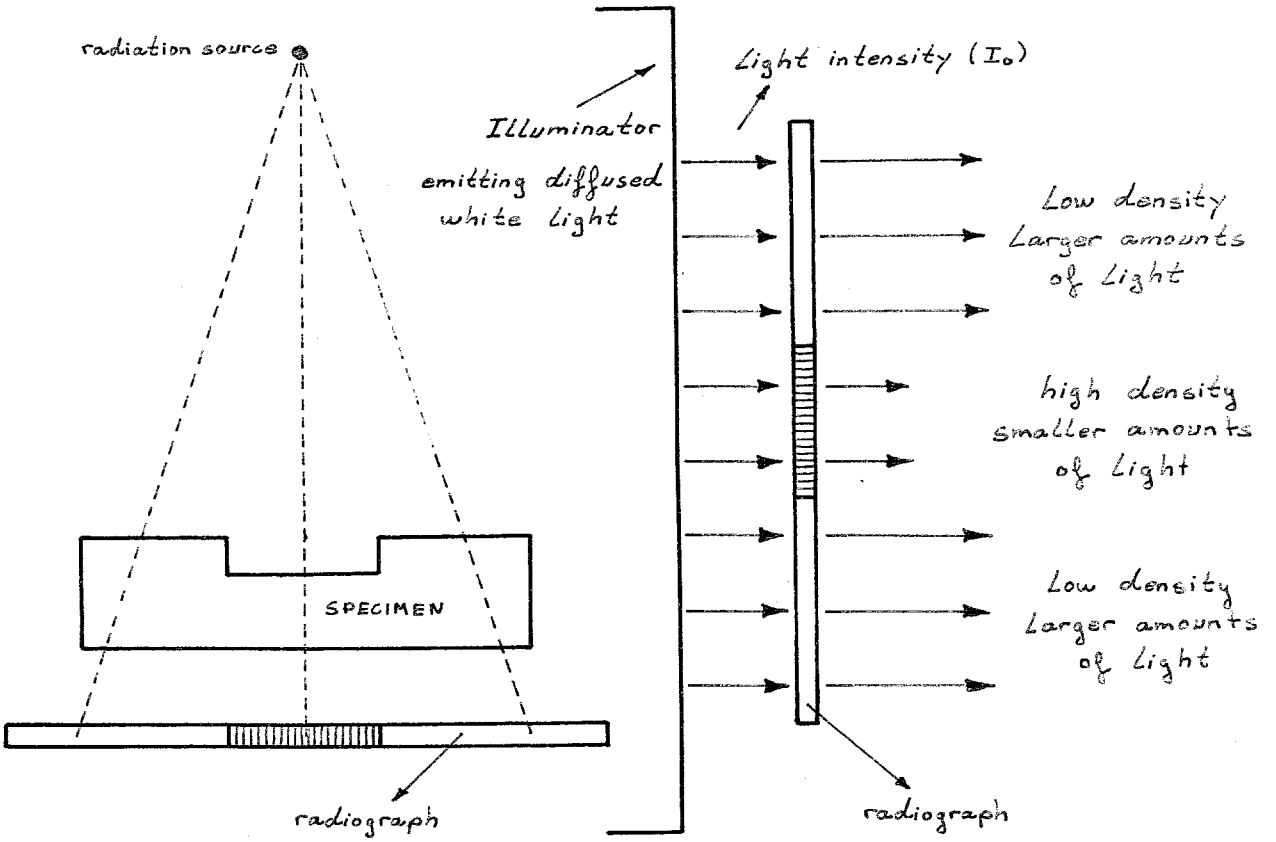


FIG. 1.4 Radiographic contrast.

The ability of a film to detect and record different radiation exposures as differences in density is called film contrast. Radiographic film is fabricated with a variety of emulsions which give different film contracts and other properties such as speed and graininess. The film contrast values of any particular film are usually expressed as a relationship between film exposure and the resulting film density. The relationship is expressed in the form of film characteristic curves. Film emulsions are classified according to their sensitivity, namely, slow, medium and fast. In general, the higher the speed of the film, the coarser the grain of the emulsion.

Screens: When a gamma ray beam comes in contact with film, less than one percent of the radiation energy available is absorbed by the film in producing an image through photographic effect. To convert the unused energy into a form that can be absorbed by film, lead screens are used. They

are usually constructed of an antimony and lead alloy that is stiffer, harder, and more wear resistant than pure lead. The screens are used in pairs, on each side of, and in close contact with, the film. Depending upon the specimen and the energy of radiation, the screens may be of varying thicknesses. The front screen in most applications is thinner than the back screen. Front screens 0.1mm thick and back screens 0.15mm thick are commonly used. Lead screens are particularly efficient because of their ability to absorb scattered radiation (soft radiation) in addition to increasing the photographic effect on the film. The increased photographic effect is a result of the release of electrons from the lead atoms when acted upon by high energy radiation. Energy from the released electrons is readily absorbed by the film emulsion, and intensifies the film response.

Penetrameters[1,4]: The penetrameter is a device whose image on a radiograph is used to determine rodiographic quality level (sensitivity). It is not intended for use in judging the size, or in establishing acceptance limits, of discontinuities. The standard penetrameter is a rectangle of metal with three drilled holes of set diameter. It is composed of material identical, or radiographically similar, to the material being radiographed. Each penetrameter is identified by a lead number (ID No.) which gives the maximum thickness of material for which the penetrameter is normally used. (Fig. 1.5).

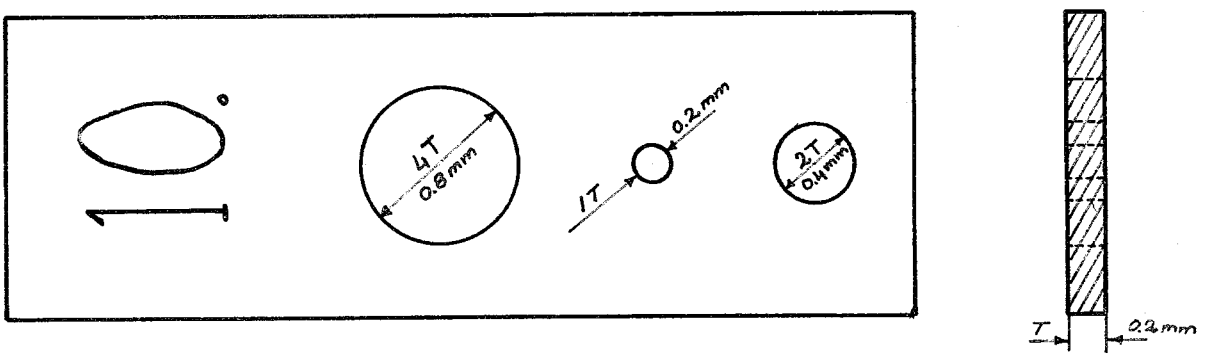


FIG. 1.5 Standard penetrameter for 10mm material.

The thickness (T) of the standard penetrameter is two percent of the thickness denoted by the ID No.[1,4], and the hole diameters are 1T, 2T, and 4T. The penetrameter is normally placed source side on top of the specimen being radiographed. Thus, it is a built-in defect of known thickness (usually two percent of Tm) and known hole diameters. The penetrameter measures the ability of the technique used to show contrast (the thickness of the penetrameter) and definition (the hole images). Standard two percent sensitivity requires the technique to image the penetrameter whose thickness is two percent of Tm, and the 2T hole of the penetrameter (penny).

1.3.3. Exposure Variables

Movement: Movement of source, specimen, or film during exposure is not usually a problem. The source switch assembly (source holder) is firmly positioned with clamps, tape, wire, etc. The specimen is positioned according to its weight, shape, and the desired angle of exposure, and the film is taped to the specimen when it is not held in position by the weight of the specimen. Any means of holding source, specimen, and film firmly in place is acceptable as long as it does not create scatter radiation problems. Movement of either source, specimen, or film during exposure blurs and distorts film image.

Source size: Source size is a factor in every radiograph and is a primary consideration in purchasing gamma ray sources. In general, the smaller the source size, the better the radiographical quality. Gamma ray source diameters vary from 10mm down to a few mm.s. Generally the radiographer has available gamma ray equipment capable of most radiographic applications, and the problem is how to make an acceptable radiograph with the equipment available. Selection of correct source-to-film distance permits good radiography with available equipment, since source size is usually within acceptable dimensions.

Source-to-film distance (SFD): In selecting an SFD, three factors must be considered: Source size, specimen thickness, and specimen-to-film distance. Optimum geometrical sharpness of the image is obtained when the radiation source is small, the distance from the source to the specimen is relatively great, and the distance from the specimen to the film is small. In the commonly used rule of thumb, SFD should not be less than ten times the specimen thickness and SFD should be greater than the widest dimension of the specimen. Also it is reasonable to place the film immediately adjacent to the specimen in terms of minimizing the specimen-to-film distance.

Film contrast, speed, and graininess: Film characteristics were detailed previously. With most industrially used films the same degree of contrast is obtainable regardless of the speed of the film selected, since the characteristic curves of the different speed films are similar in shape. Thus, the degree of resolution (sharpness) required in the radiograph fixes the speed of film that is acceptable. The time-saved, economic, consideration of fast film is secondary to the desired resolution. Fast film is seldom used.

Source energy, source strength, and time: Source energy, source strength, and time are exposure factors in gammagraphy. Source energy (wavelength of the emitted waves) is a function of the radioisotope source and remains constant. Source strength is a time-decay function of the radioisotope and must be known at the time of exposure. Since source strength and time are reciprocal functions, the length of exposure time required is determined by the source strength.

II. METHODS OF EXPOSURE TIME DETERMINATION IN GAMMAGRAPHY

2.1. General Aspects of Exposure Time Determination

There are several methods used in determination of exposure time in gammagraphy. In this study "exposure chart"[4] method (an experimental method) and the theoretical method[2] was used to determine exposure time. The theoretical method was modified using built-up factors (the alternative method) and all the methods used were compared and the results were discussed. "Exposure chart" method was studied in three sub-groups. The sub-groups differ from each other in conditions of preparation of the exposure charts and films used in the experiments. The reason of the choice of these two methods ("exposure chart" method and the theoretical method) were that they were very appropriate for computer analysis so that a realistic comparison of the methods could be done. Other methods used in gammagraphy to determine exposure time such as "reference to previous data"[4] or "characteristic curve"[4] were not appropriate for computational analysis and they are not included into this study.

2.1.1. Reference to Previous Data

Record of previous exposures can be very helpful in determining the exposure time for a specimen. Exposure of similar specimen radiographed in the past can be used as a reference for new radiographies. So, it is useful to maintain a log-book by the radiographer.

2.1.2. Characteristic Curve

Characteristic curve of a film shows the relation between the film density and relative exposure for the film. Naturally, each type of film has a different characteristic curve because of the structural specialities of films.

Characteristic curve of a film is prepared by exposing a strip of the film to gamma rays so that different parts of the film receive different exposures. The strip is normally exposed in steps so that each step receives twice the exposure of the previous step. It should also be indicated that, due to the great penetrating power of gamma rays, separate strips must be used for each exposure. The exposed strips is then developed according to the standard procedure and dried. A density step-wedge is thus obtained. After the measurement of the density of each step the values are plotted against corresponding exposures and the required characteristic curve is obtained.

Generally, characteristic curve of a film is used for determining correct exposure of samples made from mixed materials for which the exposure chart is normally not available. This method is based on a trial exposure which is estimated from the density and thickness of the material. A trial exposure of the material is taken and the density obtained is measured. This test exposure is then corrected with the help of characteristic curve of the film used to give the standart density of 2.0. While constructing a characteristic curve by using this method first, a trial exposure is taken (E_t') and gives a density (D_t) whereas the required standard density is (D). The relative exposures corresponding the densities (D_t) and (D) are read from the characteristic curve of the film used as (E_t) and (E_t'') respectively (Fig. 2.1). Then, the correct exposure (E) to obtain the required density can be found as:

$$\frac{E}{E_t'} = \frac{E_t''}{E_t} \qquad \text{(Eq. 2.1)}$$

$$E = \frac{E_t' \cdot E_t''}{E_t} \qquad \text{(Eq. 2.2)}$$

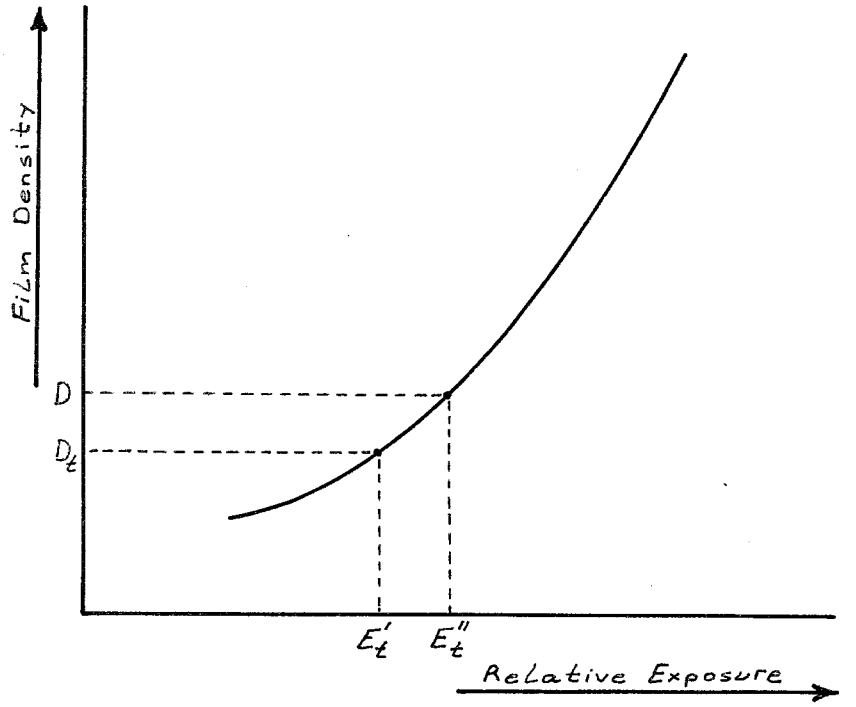


FIG. 2.1 Characteristic curve.

2.1.3. Exposure Chart

Exposure charts show the relation between specimen thickness and exposure. They are prepared experimentally and it is one of the basic methods to determine exposure time using exposure charts. Following parameters are kept fixed in preparing exposure charts in gammagraphy:

1- Gamma source.
2- Film type.
3- Film density.
4- Development (type of developer, development time and temperature of the developer).
5- Specimen material.
6- Intensifying screens.
7- Source-to-film distance (SFD).

These parameters should also be given on the exposure chart. Exposure charts can be made in two different ways:

In the first method, the exposure chart requires the characteristic curve of the film to be used and a step

wedge of the material for which a chart is to be made. The wedge should have the range of thicknesses suitable for the type of gamma ray source. For example wedge of steel with 2.0mm steps and thickness between 5-15cm would be suitable for Cobalt-60 source. First, radiograph of the metal step-wedge is taken for the radiation source chosen. The exposure should be reasonably chosen to give full spectrum of densities on the radiograph. Next, the film is processed under the standard procedure. Densities of various steps are then measured on a densitometer and tabulated against the thickness of the corresponding steps. After that, the correct exposures for the required density (2.0) are calculated for every thickness using the characteristic curve in the manner already explained. Finally, the corrected exposures are plotted against the specimen thicknesses on a semilog graph paper to obtain the required exposure chart. Fig. 2.2 shows such an exposure chart. Exposure charts can also be prepared for different film densities such as 1.5, 2.0, 2.5 densities on an exposure chart[15].

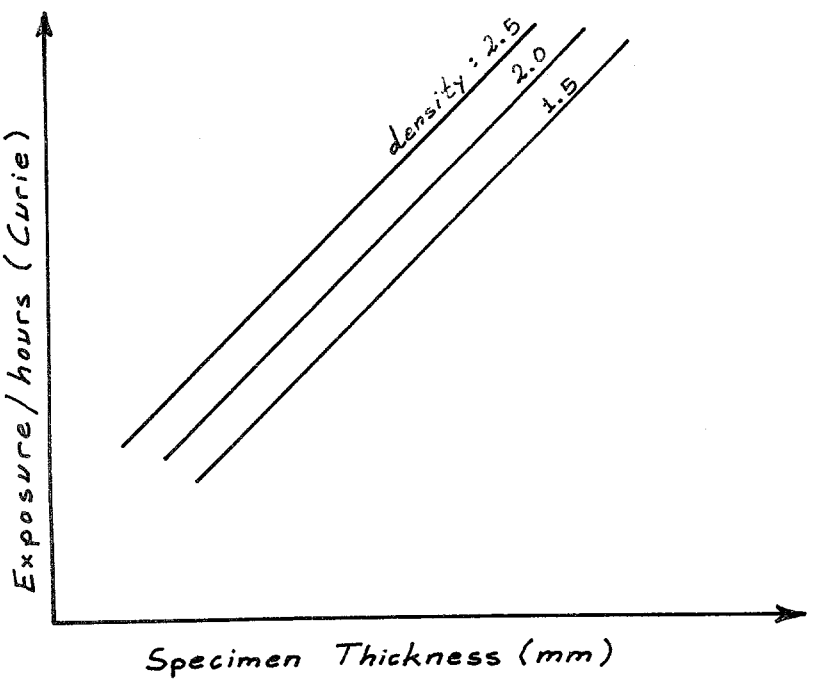


FIG. 2.2 Exposure chart.

In the second method, the exposure chart requires a number of strips (radiography film) and a step-wedge of the material for which chart is to be made. Due to the great penetrating power of gamma rays again, separate strips of the film should be used for every exposure. Otherwise, the strong exposure may spoil other parts of the film splits. Step-wedge should be chosen so as to have suitable minimum and maximum thicknesses depending on the source and the exposure should be appropriate to give full spectrum of densities on the film.

First, a radiograph of the step-wedge is taken on a strip of the film giving an exposure. Next, the radiography is repeated on a new strip of film giving an exposure almost double the previous exposure. In this way five to ten exposures are taken, every time doubling the previous exposure, so that the whole thickness range of the stepwedge is covered. The film strips are then developed under the standard procedure. After that, densities are measured and results are tabulated for each exposure. By plotting these results on a graph paper, curves similar to those of Fig. 2.3 are obtained[4].

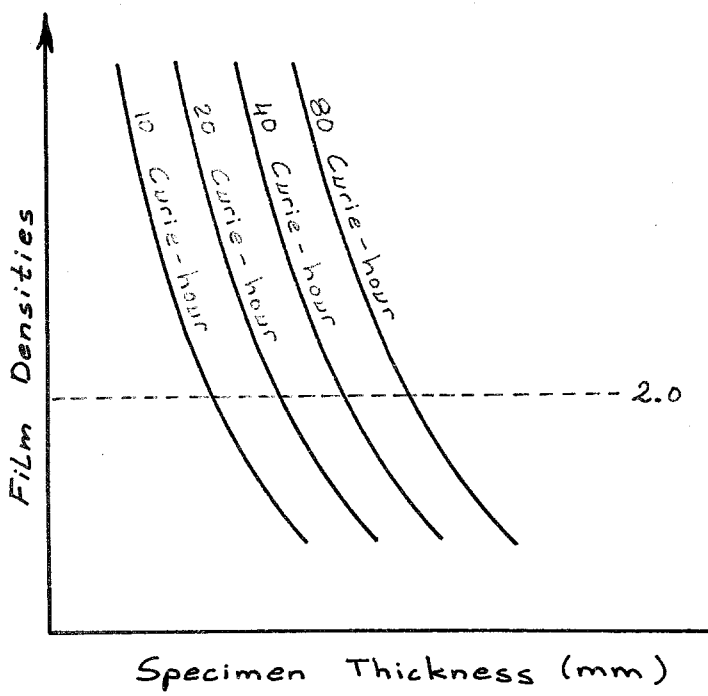


FIG. 2.3 Exposure chart.

Thickness values for various exposures that will produce the required density (2.0) are directly read from these curves. These values are then plotted against exposures on a semilog graph paper and an exposure line for the source required is obtained as shown in Fig. 2.2. Repeating this procedure, several exposure charts can be obtained for different sources and materials. Also, it is common practice to make exposure charts for gamma rays for more than one density.

Types of the exposure charts used in this study[10-12, 15]: In this study three types of exposure charts were used. Each chart differs from the others in terms of film type, film density, source-to-film distance, intensifying screens, radioactive source type and material. Specifications of the exposure charts are given in Table 2.1 and the exposure charts are shown in appendix II.

Table 2.1 Specifications of the exposure charts used in this study.

Foundation which the exp. chart was made by.	Construction specifications of the exp. chart.
KODAK	Sources : Co^{60}, Cs^{137}, Ir^{192} Material : Steel Film Type : Industrex A Film Density: 2.5 SFD : 100cm Intensifying Screens : Front and back lead screens. Development of the Film: Standard processing.
GEVAERT	Sources : Co^{60}, Cs^{137}, Ir^{192} Material : Steel Film Type : Structurix D7 Film Density: 2.0 SFD : 50cm

Table 2.1 (continued)

	Intensifying Screens : 100 μ front, 150 μ back lead screens. Development of the Film: Standard processing.
AERE	Sources : Co^{60}, Cs^{137}, Ir^{192} Material : Steel Film Type : Structurix D7 Film Density: 2.0 SFD : 30cm Intensifying Screens : 100 μ front, 150 μ back lead screens. Development of the Film: Standard processing.
CGR	Source : Ir^{192} Material : Steel Film Type : Structurix D10 Film Density: 2.0-3.0 SFD : 100cm Intensifying Screens : 100 μ front, 150 μ back lead screens. Development of the Film: Standard processing.

2.2. Determination of Exposure Time by Experimental Method[15]

This method is based on exposure chart thecnique and called as the "Experimental Method" because exposure charts are prepared with experimental methods.

The experimental method can be explained as:

$$Q_1 \, D_2^2 \, h_1 = Q_2 \, D_1^2 \, h_2 \qquad \text{(Eq. 2.3)}$$

where:

Q_1 = Exposure in curies read from the exposure chart for a required specimen thickness.

Q_2 = Source activity in curies available for the radiography.

D_1 = SFD used in preparing of the exposure chart (cm).

D_2 = SFD to be used in the radiography (cm).

h_1 = Exposure time used in preparing the exposure chart (min).

h_2 = Calculated exposure time from Eq. 2.3 for the required specimen thickness.

Eq. 2.3 shown above, is based an inverse square law so that exposure time is inversly proportional to the spuare of SFD. There are some other factors that affect the calculations and require a few modifications on Eq. 2.3. These factors are:

1- Density of the film: Radiographic films have to have a density between 1.5 to 3 for a good definition, and if the required density is different from the density indicated on the exposure chart, a film density factor (FDSFA) should be added to Eq. 2.3 to correct this difference in the film densities (Table 2.2).

Table 2.2 Film density factors (FDSFA)[1].

Density	1.0	1.5	2.0	2.5	3.0
FDSFA	0.43	0.71	1.0	1.30	1.62

2- Film speed factor: Exposure charts are prepared for a specific film and each film has a different nature and so a different film speed. If the film to be used in radiography has a different speed than the film used in preparing the exposure chart, a film speed factor (F) should be added to Eq. 2.3. Film speed factors of some radiographic films are given in Table 2.3. Adding these factors to Eq. 2.3, it becomes:

$$h_2 = \frac{Q_1 \times D_2^2 \times h_1 \times FDSFA \times F}{Q_2 \times D_1^2} \qquad \text{(Eq. 2.4)}$$

Table 2.3 Film speed equivalences[4-6].

Kodak Films	Relative Speeds of the Films	Film Speed Factors	Geavert Films
	0.5	128	Structurix D2 (single coat)
R	1	60 ÷ 64	Structurix D2
Industrex M	4	15 ÷ 16	Structurix D4
M	4	16 ÷ 18	
	8	8	Structurix D5
Industrex A	16	4	Structurix D7
Industrex C	16	3.5 ÷ 4	
AA	16	4	
Industrex D	32	1.8 ÷ 2	
Kodirex	64	0.8 ÷ 1.2	
KK	64	1	Structurix D10

Eq. 2.4 is the main formula of ETD with the exposure chart method and using this equation all exposure chart data were computerized for the later steps in the study.

2.3. Determination of Exposure Time by Theoretical Method[2]

The theoretical method[2] inuolves the relation between the amount of radiation exposure and the film density. Film density is a quantity which is the ratio of logarithmic rate of the visible light intensity with no radiograph between the light source and photomultiplier tube to the visible

light intensity that passes through the radiograph at the point of interest. Specifically, film density is defined as,

$$D = \log (J_o / J) \qquad \text{(Eq. 2.5)}$$

A film density of two is usually required in radiography when the human eye is used to inspect the final radiograph. Higher film densities are preferable if instrumental methods or intense illuminators are used for inspection of the film.

On the other hand, the amount of visible light transmitted by an exposed film is a function of the amount of silver ion that has been reduced in the film during the exposure. The rate of silver reduction in a film is given by a first-order differential equation:

$$\frac{da}{dt} = K_1 I (A-a) \qquad \text{(Eq. 2.6)}$$

where:

a = Amount of reduced silver (gr).
t = Elapsed exposure time.
K_1 = Efficiency of the film for the radiation being used, a constant for a given film and radiation energy.
I = Radiation intensity (dis/sec).
A = Total amount of silver initially present in the film that can be reduced (gr).

Eq. 2.6 can be solved introducing a new variable b, defined by $b = A-a$, for a initially zero.

$b = A-a$ taking the derivative of the equation,

$db = -da$ substituting these terms into Eq. 2.6,

$$-\frac{db}{b} = K_1 I\, dt$$ and integrating both sides,

$$-\int \frac{db}{b} = K_1 I \int dt \quad : \quad -\ln b + C = K_1 I\, t$$

$$-\ln (A-a) + C = K_1 I\, t \qquad \text{(Eq.2.7)}$$

for $a = 0$ at $t = 0$

$C = \ln A$ substituting C into Eq. 2.7

$-\ln (A-a) + \ln A = K_1 I\, t$ solving the equation for a,

$$a = A\,(1-e^{-K_1 I\, t}) \qquad \text{(Eq. 2.8)}$$

The amount of transmitted light is also an exponential function of the amount of reduced silver present in the exposed film:

$$\frac{J_o}{J} = e^{-K_2 a} \qquad \text{(Eq. 2.9)}$$

where K_2 is a constant.

The film density for a given film can be explained as a function of the amount of exposure by substituting Eq. 2.8 into Eq. 2.9 and substituting the subsequent equation into Eq. 2.5,

$$\frac{J_o}{J} = \exp\left(-K_2 A \left(1-e^{-K_1 I t}\right)\right)$$

$$D = \log\left\{\exp\left(-K_2 A \left(1-e^{-K_1 I t}\right)\right)\right\} \qquad \text{(Eq. 2.10)}$$

Since $\ln x = 2.303 \log x$, the equation can be written as,

$$D = \frac{1}{2.303} \ln\left\{\exp\left(-K_2 A \left(1-e^{-K_1 I t}\right)\right)\right\}$$

$$D = \frac{-K_2 A \left(1-e^{-K_1 I t}\right)}{2.303} \qquad \text{(Eq. 2.11)}$$

Defining a new constant K_3 as $-K_2 A / 2.303$, the Eq. becomes,

$$D = K_3 \left(1-e^{-K_1 I t}\right) \qquad \text{(Eq. 2.12)}$$

This equation with $K_3 = 3.44$ and $K_1 = 0.01$ is used to calculate values of D that are compared with the experimental values of D for type F film and the agreement is quite good[2]. Solving (Eq. 2.12) for the amount of exposure,

$$It = \frac{-\ln\left(1-D / K_3\right)}{K_1} \qquad \text{(Eq. 2.13)}$$

An expression for the source intensity, I, on the film should include the effect of specimen attenuation and the solid angle intercepted by the film,

$$I = \frac{S\ e^{-\mu x}}{4\pi\ SFD^2} \quad dis\ /\ sec\ /\ cm^2 \qquad \text{(Eq. 2.14)}$$

where:
S = Source activity (dis / sec).
μ = Absorption coefficient for the source and specimen (cm^2 / gr).
x = Specimen density thickness (gr / cm^2).
SFD = Source-to-film distance (cm).

Substituting Eq. 2.14 for I in Eq. 2.13 and solving for t gives,

$$t = \frac{-4\pi\ \ln\ (1-D\ /\ K_3)\ SFD^2\ e^{\mu x}}{K_1\ S} \qquad \text{(Eq. 2.15)}$$

when $f\ (D) = -\ (4\pi\ /\ K_1)\ \ln\ (1-D\ /\ K_3)$ is substituted into Eq. 2.15, this equation simplifies to,

$$t = \frac{f(D)\ SFD^2\ e^{\mu x}}{S} \qquad \text{(Eq. 2.16)}$$

Where f(D) is a function that depends on the film density, the type of film being used, and the radioactive source. These factors for various films, film densities, and radioactive sources are listed in Table 2.4[2].

Another important point in use of Eq. 2.16 is the effect of scattered radiation that causes an exposure on films. A built-up factor or an "effective absorption coefficient", (EAC), should be used to compansate for this phenomenon. In the theoratical method, "effective absorbtion

coefficient" is used for the effect of scattered radiation[2]. The EAC's of commonly used radioisotopes are given in Table 2.5.

Table 2.4 Film factors for commonly used film types, film densities, and radiography sources[2].

Radiography source	Film type	Film factor, $10^9 cm^{-2}$		
		Film density		
		1.5	2.0	3.0
Co-60	Eastman KK-Structurix D10	2.8	4.5	11.0
Co-60	Eastman AA-Structurix D7	8.6	16.0	48.0
Co-60	Eastman M -Structurix D4	52.0	70.0	116.0
Cs-137	Eastman KK-Structurix D10	8.1	13.0	31.0
Cs-137	Eastman AA-Structurix D7	24.0	44.0	138.0
Cs-137	Eastman M -Structurix D4	148.0	200.0	330.0
Ir-192	Eastman KK-Structurix D10	7.6	12.0	30.0
Ir-192	Eastman AA-Structurix D7	23.0	42.0	130.0
Ir-192	Eastman M -Structurix D4	140.0	190.0	315.0

Table 2.5 Effective absorption coefficients for radiography sources[2].

Source	Effective absorption coefficient, cm^2 / gr
Co-60	0.035
Cs-137	0.042
Ir-192	0.046

2.4. Determination of Exposure Time by Alternative Method

At this stage of the study, the theoretical method was improved by adding the built up factor into the system. The reason for the use of the build up factor is to increase the sensitivity of the theoretical method and to minimize the effect of scattering on exposure. The new - build up factor added - theoretical method was submitted under the name "the alternative method" and was included in the computer programme for the analysis and comparison of the methods.

The alternative method differs from the theoretical method in such a way that, the EAC used in the theoretical method has a compensative function instead of build up factor. It can be considered as an average build up factor since the $EAC^{(2)}$ is a constant for all material thicknesses for a definite source. The build up factor is variable for all materials, thicknesses and source energies. So the EAC could not compensate for the scattering radiation because of its constant structure since the phenomena of "scattering" is directly proportional to the thickness and density of the specimen and to the source energy. The alternative method uses the "linear absorption coefficient", LAC, instead of the EAC and compensates the "scattering" phenomena best since its LAC and its build up factor is variable according to changing source energy, material and material thickness. Build up factor can be explained with the attenuation of radiation.

The attenuation of radiation by an absorber is defined by the equation,

$$I = I_o \, e^{-\mu x} \qquad \text{(Eq. 2.17)}$$

where:
I_o = Intensity of incident radiation.
I = Intensity of transmitted radiation.

x = Thickness of absorber (specimen)
μ = Linear absorption coefficient for material (Table 2.8).

Eq. 2.17 is appropriate for narrow beam absorption. But in radiography the conditions usually fail to meet the ideal conditions of narrow beam attenuation. The sources of radiation may not approximate points, and broad beam, wide, thick absorbers are usually involved. In such cases gamma rays may be scattered to the film as well as away from it and cause an extra exposure on the film. A correction must be made to allow for the effect of the scattered radiation. Eq. 2.17 now becomes,

$$I = I_o \, B \, e^{-\mu x} \qquad \text{(Eq. 2.18)}$$

where B is the build-up factor. The value of the build-up factor depends upon the absorber material, energy of the radiation, and the source arrangement, absorber, and film. Table 2.6 shows the build-up factors of steel for various energies.

Table 2.6 Dose build-up factor for a point isotropic source[14], Material : Steel.

MeV	μx *						
	1	2	4	7	10	15	20
0.5	1.98	3.09	5.98	11.7	19.2	35.4	55.6
1.0	1.87	2.89	5.39	10.2	16.2	28.3	42.7
2.0	1.76	2.43	4.13	7.25	10.9	17.6	25.1
3.0	1.55	2.15	3.51	5.85	8.51	13.5	19.1
4.0	1.45	1.94	3.03	4.91	7.11	11.2	16.0
6.0	1.34	1.72	2.58	4.14	6.02	9.89	14.7
8.0	1.27	1.56	2.23	3.49	5.07	8.50	13.0
10.0	1.20	1.42	1.95	2.99	4.35	7.54	12.4

* μx = mass absorption coefficient (μ / ρ) x material thickness (cm) x material density (gr/ cm^3).

Applying the build-up factor to Eq. 2.16,

$$t = \frac{f(D)\ SFD^2 \sum_{E=1}^{N} (e^{\mu x} / B)}{S} \qquad \text{(Eq. 2.19)}$$

where:

f (D) = is a function depending on the film density, the type of film being used, and the radioactive source.

SFD = is source-to-film distance (cm).

E = is the energy (MeV) components of the radioactive source.

μ = is linear absorption coefficient (cm^{-1}).

x = is material thickness (cm).

B = is build -up factor.

S = is source activity (dis / sec).

Gamma ray energies of commonly used radioisotopes are given in Table 2.7[13]. Using this table linear absorption coefficients (Table 2.8) and mass absorption coefficients (Table 2.9) can be found and then using this data build-up factors for each gamma-ray energy of the radioisotope being used can be determined. If the radioisotope used has gamma ray energies more than one, all the build-up factors and linear absorption coefficients corresponding to each energy value should be used additively in Eq. 2.19.

Table 2.7 Gamma ray energies of some radioisotopes for use in Eq. 2.19[13].

Radioisotope	Energies (MeV)
Co-60	1.173 (100), 1.332 (100)
Ir-192	0.310 (170), 0.468 (65)
	0.588 (8) , 0.610 (25)
Cs-137	0.662 (95)

Table 2.8 Gamma ray linear absorption coefficients (cm^{-1})[14].

MeV	Mg	Al	Fe	Cu	Sn	Pb	Concrete
0.1	.279	.435	2.704	3.814	11.53	59.99	.397
0.15	.235	.362	1.438	1.840	4.109	20.87	.327
0.2	.212	.324	1.085	1.313	2.211	10.16	.291
0.3	.185	.278	.833	.965	1.117	4.037	.251
0.4	.1643	.2489	.7223	.8183	.795	2.359	.2242
0.5	.1497	.2268	.6508	.7325	.6466	1.644	.2045
0.6	.1384	.2098	.5989	.6709	.5663	1.293	.1889
0.8	.1217	.1844	.5219	.5842	.4722	.9480	.1659
1.0	.1092	.1658	.4677	.5226	.4145	.7757	.1492
1.25	.1975	.1480	.4174	.4654	.3656	.6452	.1332
1.5	.0891	.1350	.3812	.4252	.3350	.5806	.1215
2	.0770	.1166	.3333	.3734	.2978	.5182	.1046
3	.0627	.0953	.2837	.3189	.2678	.4774	.0853
4	.0548	.0837	.2594	.2948	.2591	.4763	.0745
5	.0498	.0761	.2460	.2823	.2591	.4831	.0674
6	.0463	.0713	.2389	.2760	.2613	.4944	.0630
8	.0421	.0651	.2319	.2707	.2686	.5205	.0571
10	.0397	.0618	.2311	.2725	.2795	.5545	.0538

Table 2.9 Gamma ray mass absorption coefficients (cm^2 / gr)[14].

MeV	Mg	Al	Fe	Cu	Sn	Pb	Concrete
0.1	.160	.161	.344	.427	1.58	5.29	.169
0.15	.135	.134	.183	.206	.563	1.84	.139
0.2	.122	.120	.138	.147	.303	.896	.124
0.3	.106	.103	.106	.108	.153	.356	.107
0.4	.0944	.0922	.0919	.0916	.109	.208	.0954
0.5	.0860	.0840	.0828	.0820	.0886	.145	.0870
0.6	.0795	.0777	.0762	.0751	.0776	.114	.0804
0.8	.0699	.0683	.0664	.0654	.0647	.0836	.0706
1.0	.0627	.0614	.0595	.0585	.0568	.0684	.0635
1.25	.0560	.0548	.0531	.0521	.0501	.0569	.0567
1.5	.0512	.0500	.0485	.0476	.0459	.0512	.0517
2	.0442	.0432	.0424	.0418	.0408	.0457	.0445
3	.0360	.0353	.0361	.0357	.0367	.0421	.0363
4	.0315	.0310	.0330	.0330	.0355	.0420	.0317
5	.0286	.0282	.0313	.0316	.0355	.0426	.0287
6	.0266	.0264	.0304	.0309	.0358	.0436	.0268
8	.0242	.0241	.0295	.0303	.0368	.0459	.0243
10	.0228	.0229	.0294	.0205	.0383	.0489	.0229

III. EXPERIMENTAL WORK

One of the most important steps of the study was the experiments. The aim of this step was to determine the most sensitive and reliable ETD method for a definite source, material and film taking a series of radiographs using these methods. The chosen method could easily be adapted to other sources, materials and films by using the appropriate equivalence factors[1-6]. The experiments were performed at the industrial application laboratories of Çekmece Nuclear Research and Training Center. A Cobalt-60 source (initial activity 29 Ci) with its camera system (Fig 3.1 and 3.2), structurix D7 type (medium speed) films and several thicknesses of steel as specimen material were used in the experiments. There were some focal points in taking the radiographs that had been directly affecting the results during the experiments. These are:

1- Measurement of the thickness of the specimen to be radiographed in millimetrical sensitivity (∓ 0.5mm).
2- Adjustment of SFD in centimetrical sensitivity (∓ 0.5cm).
3- Proper use of the Co-60 camera system in terms of geometric construction of the system and timing.
4- Development conditions during processing of the films.

The experimental part of the study was performed mainly in two steps. At first, several radiographs were taken by using each method (exposure chart, theoretical and alternative methods). Then the films taken, were processed and their densities were measured with a densitometer. It was shown that the best result had been obtained from the alternative method (Table 3.1, Fig. 3.3 and 3.4) and the worst was from the exposure chart method. After that, the results were compared with the computer outputs and the exposure chart method was eliminated from the experiments as a result of comparison of the results. Since the computer outputs were indicating a continuous great difference between the exposure chart method and the alternative method.

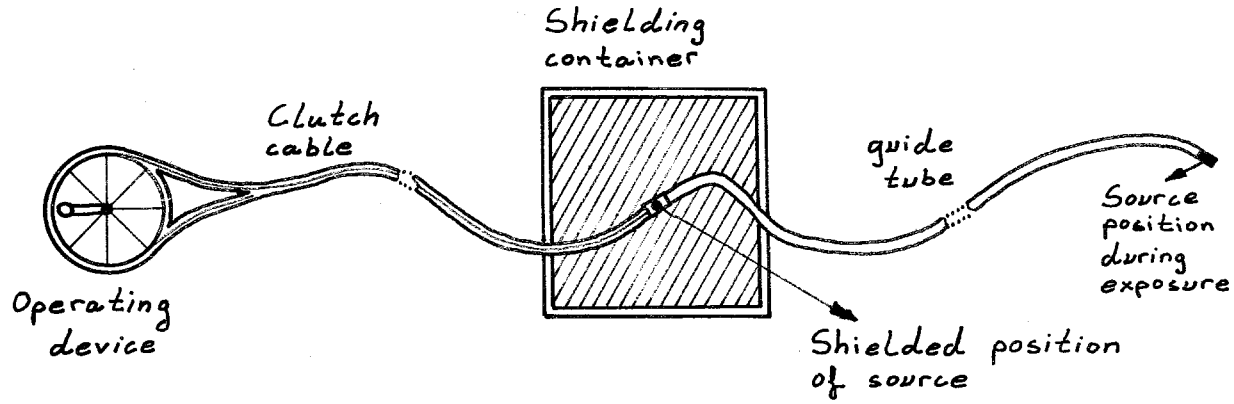


FIG. 3.1 Remote control gamma projector.

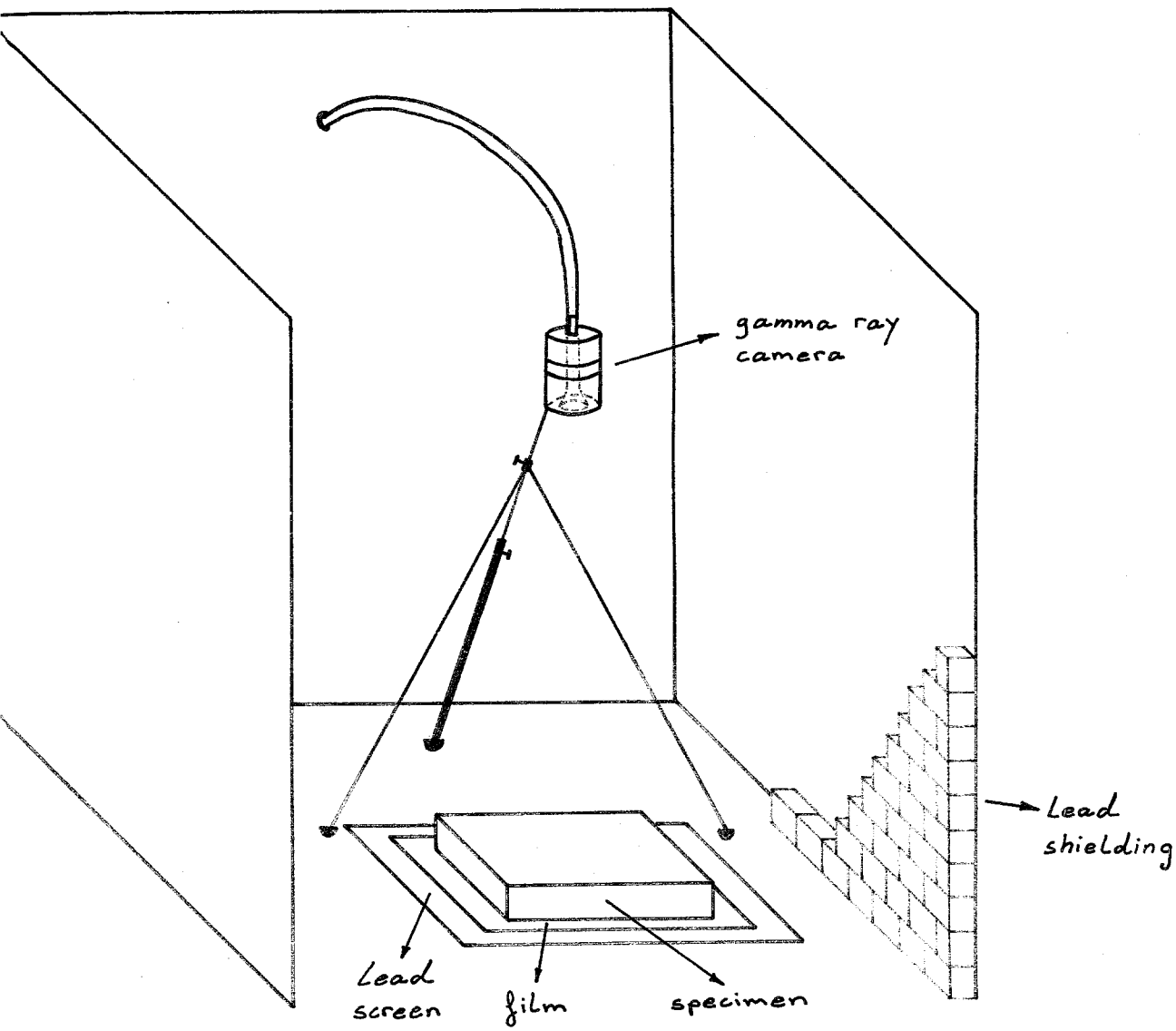
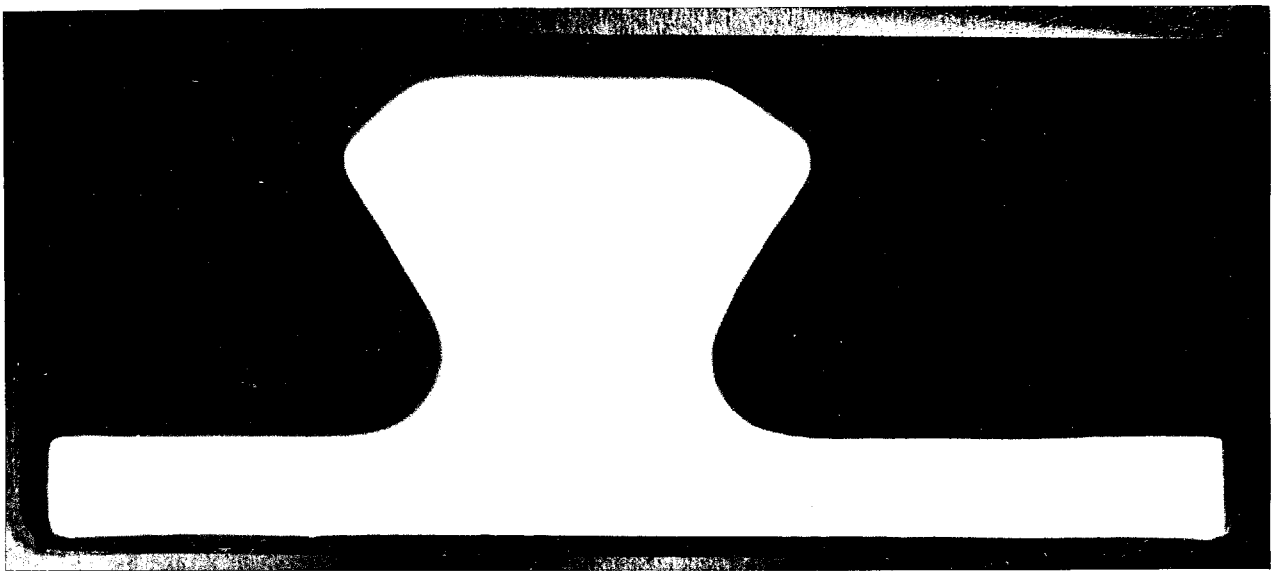


FIG. 3.2 Radiography set used in the experiments.

Table 3.1 Experimental results.

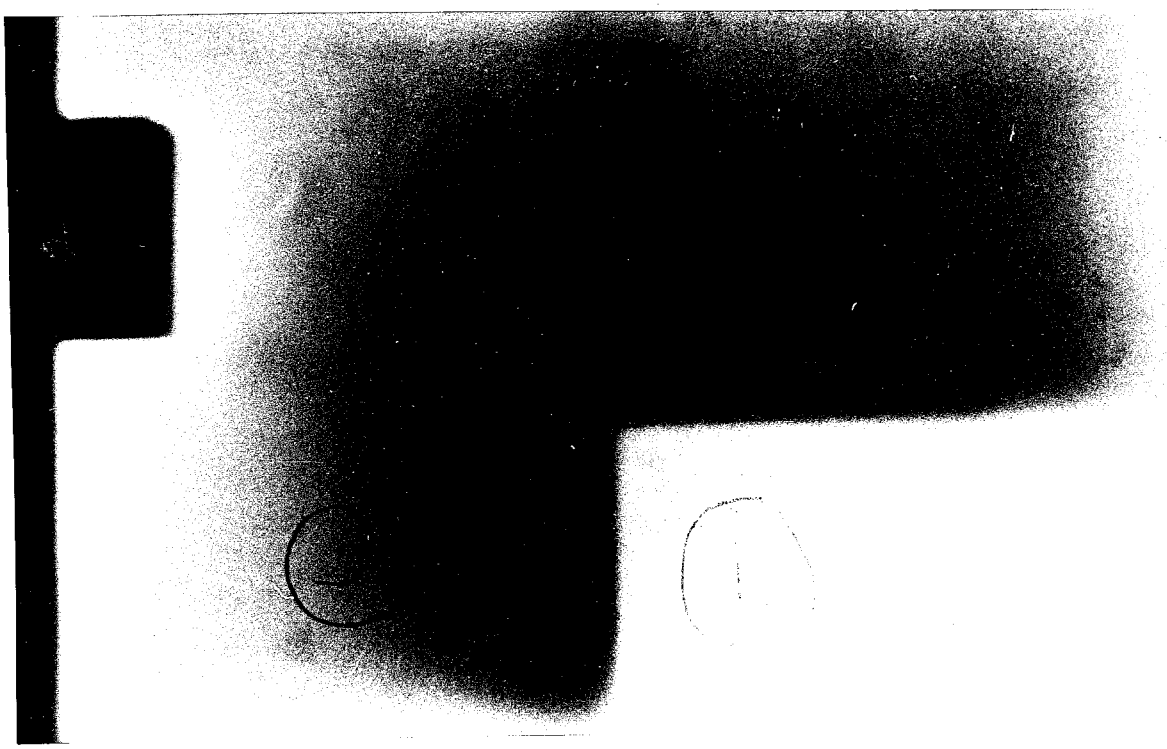
Radioactive source : Cobalt-60
Activity : 24.3 Curie
Film : Structurix D7

Specimen Material	Material Thickness (mm)	SFD (cm)	Exposure Time (min.)	ETD Method	Required Density	Measured Density	Deviati %
Steel	74	56	14	Exposure chart "Geavert"	2	2.5	25 +
Steel	74	56	6.2	Theoretical M.	2	1.6	20 -
Steel	74	56	9.0	Alternative M.	2	2.1	5 +
Steel	120	100	104	Alternative M.	2	2.0	0
Steel	74	75	16	Alternative M.	2	2.0	0
Steel	55	75	6.7	Alternative M.	1.5	1.5	0
Steel	37	75	6.7	Alternative M.	2.4	2.3	4 -
Steel	82	82	14.9	Alternative M.	1.5	1.55	3.
Steel	100	100	45.5	Theoretical M.	2.5	2.0	20 -
Steel	100	100	71.6	Alternative M.	2.5	2.55	2 +
Steel	60	75	7.6	Theoretical M.	2	1.65	17.
Steel	60	75	10.7	Alternative M.	2	2.0	0
Steel	50	75	7.0	Theoretical M.	2.3	1.80	22 -
Steel	50	75	9.8	Alternative M.	2.3	2.35	2 +
Steel	75	75	11.5	Theoretical M.	2	1.55	22 -
Steel	75	75	16.6	Alternative M.	2	2.0	0



Radiation source	: Cobalt-60
R. source astivity	: 24.3 Curie
Material	: Steel
Material thickness	: 74mm
SFD	: 75cm
ETD method	: Alternative method
Exposure time	: 16 min.
Film type	: Structurix D7
Required film density	: 2.0
Measured film density	: 2.0
Deviation (percent)	: 0

FIG. 3.3 A sample radiograph taken by using alternative method.



Radiation source	:	Cobalt-60
R. source activity	:	24.3 Curie
Material	:	Steel
Material thickness	:	Point 1 and 2 : 55mm
	:	Point 3, 4 and 5 : 37mm
SFD	:	75cm
ETD method	:	Alternative method
Exposure time	:	6.7 min.
Film type	:	Structurix D7
Required film density	:	Point 1 and 2 : 1.5
	:	Point 3, 4 and 5 : 2.3
Measured film density	:	Point 1 and 2 : 1.5
	:	Point 3, 4 and 5 : 2.3
Deviation (percent)	:	0

FIG. 3.4 A sample radiograph taken by using alternative method.

It had meant that the exposure chart method would consistently give inaccurate results.

In the second step of the experiments the alternative method and the theoretical method were examined with a wide range of specimen thicknesses (37-120mm) since the methods had been giving acceptable results in only a definite thickness range of the material. Several radiographs were taken for several specimen thicknesses to avoid this source of error and to observe the sensitivities of the two methods with changing specimen thickness. The results obtained from the experiments (Table 3.1) showed that the most sensitive and reliable method was the alternative method with ∓ 0.5 percent deviation in required film density. This is a considerably better result since the deviation of the exposure chart method was $< 25^{+}$ percent and the deviation of the theoretical method was $< 20^{-}$ percent.

IV. DISCUSSION AND CONCLUSION

At the beginning of the study the aim was to evaluate the ETD methods and computerizing them to construct ETD tables for the workers in the field of radiography. While examining the theoretical method[2], the non usage of build-up factor in the method focused the study on this factor. This was very important because the radiation passing and scattering through the specimen was causing an extra exposure on the film. The factor "effective absorption coefficient", EAC, used in the theoretical method could not compensate for the scattering radiation. The phenomena "scattering" is directly proportional to the thickness and density of the specimen and to source energy. However the EAC had been kept constant according to the thickness. As a matter of fact the results observed from the experiments (Table 3.1) had shown the insufficiency of the theoretical method.

The study on build-up factor caused the development of the alternative method. The two methods are the same in general. But the alternative method covers the build-up factor and uses the "linear absorption coefficient", LAC, instead of the EAC. The usefulness of the build-up factor had been shown clearly during the experiments (Table 3.1). The results obtained from the experiments showed that the most sensitive and reliable method was the alternative method with $\mp$ 0.5 percent deviation in required film density where the deviation of the theoretical method was $< 20^{-}$ percent.

On the other hand the exposure chart methods used in the study did not give the reliable results (deviation was $< 25^{+}$ percent). Since they are constructed experimentally they should be used to have only a general idea in exposure time, not for a precise calculation. Another reason which obstructs sensitive results from exposure charts, is the semi-logarithmic structure of them.

Computerization of the ETD methods made possible to analyze the methods in a wide scale. Some ETD methods could had been giving acceptable results in a definite thickness range of the material, but they could be insufficient in general. To avoid this kind of error, the ETD methods were examined taking radiographs in a wide thickness range of the material to determine the sensitivity of the methods.

The experiments were performed by using a Co-60 source. A little arrangement in film factor (FF) which covers the effect of source type, film type, and film density, was necessary to make the alternative method more sensitive due to the use of build-up factor. The arrangement in the film factor was made according to the usage of Co-60 source and the necessary changes were made in the constructed exposure tables. Ir-192 and Cs-137 are not included in the study as radiation sources but ETD tables according to the alternative method are also constructed for these sources. It is a suggestion that, all the experiments made for Co-60 should be repeated for Ir-192 and Cs-137 to determine the necessary changes in the film factor to obtain the best and most reliable results.

The last step of the study was to construct exposure tables. The tables were prepared for the commonly used radiographical conditions and could easily be applied to other radiographic conditions by using the necessary conversion factors*. The tables were constructed according to 1- exposure variables (for steel), 2- densities of specimen materials, so as exposure time for different kind of materials could easily be found referring to "2". Finally the submitted tables were given also in the form of "exposure charts" by using the least squares method** and semi-log form, for common studies in this field.

*The conversion factors are given in appendix I.
**The least squares method is explained in appendix III.

APPENDIX I

Computer programme

APPENDİX I

Computer Programme

Function of the programme: A computer programme was improved to analyze the differences between the ETD methods. The flow-chart of the programme is shown in Table I-1. The functions of the programme are, 1- to calculate exposure time using several ETD methods and to compare them, 2- to calculate exposure time of the specimen materials with the densities of between from 1 to 12 gm / cm^3.

In the first part of the computer programme, six different ETD methods were used, namely four exposure chart methods, theoretical method and alternative method. Exposure charts were of Kodak, Agfa-Gevaert, CGR and AERE (Appendix II).

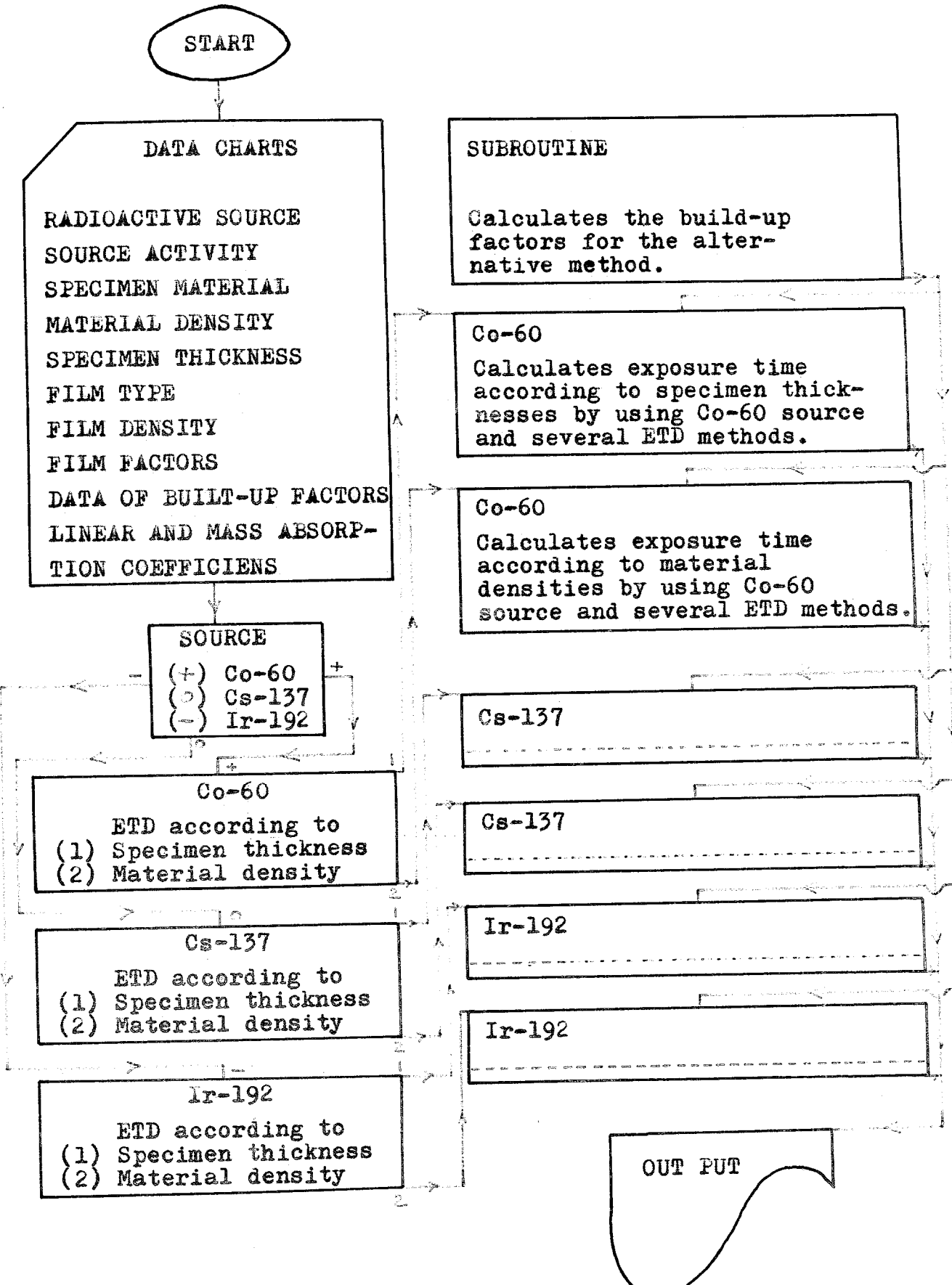
These exposure curves are in-corporated into the programme in the linear equation* of the form $y = mx + b$.

Formulation of the other two theoretical methods were mentioned in chapter two. The first part of the computer programme was constructed to calculate exposure times of the specimen having thicknesses from 10mm to 200mm. The programme can be used for the radioactive sources Co-60, Cs-137, Ir-192 with various activities changing from 10 Ci to 50 Ci, and several type of films, the required film densities and source-to-film distances can easily be adapted to the programme

In the second part of the computer programme, using the alternative method, exposure times were calculated for several materials of densities ranging from 1 to 12 gr / cm^3. This part of the programme has the same function as part one. The "zeros" in the out-put tables indicates, that specimen thicknesses are not appropriate for radiography with that source.

*The details are given in appendix III.

Table I-1 The flow chart of the computer programme.



Meaning of the phrases used in the programme:

RADSO : radiation source (Co-60 → 1, Cs-137 → 2, Ir-192 → 3).
DENMA : density of the specimen material (gr / cm^3).
SOACT : activity of the radioactive source (Ci).
M : minimum specimen thickness which can be radiographed. in standard two percent sensitivity (mm).
N : maximum specimen thickness which can be radiographed in standard two percent sensitivity (mm).
D : film density (required).
F : film speed factor used by exposure chart method.
FF : film factor used by the theoretical method.
FDSFA : film density factor. This factor was changed into a linear equation by using the least-squares method.
VUCO : effective absorption coefficient for Co-60 (cm^2 / gr).
VUCSS : effective absorption coefficient for Cs-137 (cm^2 / gr).
VUIR : effective absorption coefficient for Ir-192 (cm^2 / gr).
VUCO1 : linear attenuation coefficient for Co-60 (cm^{-1}).
VUCO2 : linear attenuation coefficient for Co-60 (cm^{-1}).
VUCS : linear attenuation coefficient for Cs-137 (cm^{-1}).
VUIRR : linear attenuation coefficient for Ir-192 (cm^{-1}).
MUM : mass attenuation coefficients of the relevant sources (cm^2 / gr).
TKMA : specimen thickness (mm).
TKMA2 : steel equivalent specimen thickness (mm).
SFD : source-to-film distance (cm).
EQU : steel equivalence factor. This factor was changed into a linear equation form by using the least-squares method

EXCO1, EXIR1, EXCS1 : required exposure calculated from the exposure chart of KODAK.

EXCO2, EXIR2, EXCS2 : required exposure calculated from the exposure chart of AGFA-GEAVERT.

EXCO3, EXIR3, EXCS3 : required exposure calculated from the exposure chart of AERE.

EXIR6 : required exposure calculated from the exposure chart of CGR.

ETCO1, ETCO2, ETCO3, ETIR1, ETIR2, ETIR3, ETIR6, ETCS1, ETCS2, ETCS3 : exposure time, calculated by using relevant exposures.

ETCO4, ETIR4, ETCS4 : exposure time, calculated by using the alternative method.

ETCO5, ETIR5, ETCS5 : exposure time, calculated by using the theoretical method.

SUBROUTINE BUILT : this subroutine calculates the necessary build-up factors for the alternative method by making extrapolations from the build-up table.

Use of the exposure time tables: There are four variables used in the tables. These are source astivity, film type, film density and source-to-film distance. The tables are constructed for the most common radiography working conditions and changes needed can easily be implemented through the use of the computer programme in the variables for the further analysis. But in case of a practical study the following procedure is suggested for manual changes in the variables.

1- Change in source activity : divide the source activity of the table by the new activity and multiply by the relevant exposure time.

2- Change in source-to-film distance : divide the square of the new SFD by the square of the SFD read from the table and multiply by the relevant exposure time.

3- Change in film type : divide the speed factor of the new film by the speed factor of the film of the table and multiply by the relevant exposure time.
Note that all the tables were prepared for the films with lead screens. In case a film without lead screens is used, the exposure time should be increased by a factor of 1.5 - 2.

4- Change in film density : divide the new film density by the film density read from the table and multiply by the relevant exposure time.

```
100 C      THIS COMPUTER PROGRAMME IS PREPARED
110 C        FOR EXPOSURE TIME CALCULATIONS
120 C
130        REAL BU(5,8),BLDUP(4),MUM(4),MEV(4),A(4),EXPSR(30)
140        READ(5,100) ((BU(I,J),J=1,8),I=1,5)
150 100    FORMAT(8F8.2)
160        RADSO=3.
170        DENMA=7.86
180        SOACT=30.0
190        M=12
200        N=100
210        D=2
220        F=1
230        FF=42
240        FDSFA=0.594*D-0.176
250        K1=2
260        L1=3
270        VUCO=0.035
280        VUCO1=0.4329
290        VUCO2=0.4055
300        VUCS=0.5750
310        VUCSS=0.042
320        VUIR=0.046
330        VUIRR=0.7389
340        WRITE(6,200)
350 200    FORMAT(1H1,4X,'RADIOACTIVE SOURCE : IRIDIUM 192',//,
360       $5X,'R.SOURCE ACTIVITY  : 30.0 CURIE',//,
370       $5X,'FILM TYPE          : STRUCTURIX D7',//,
380       $5X,'FILM DENSITY       : 2',/////,
390       $5X,'CALCULATED EXPOSURE TIMES FOR THE MATERIALS WITH',1X,
400       $'DENSITIES FROM 1.0 GR/CM3 TO 10.0 GR/CM3',/////,
410       $5X,'MATERIAL',6X,'SFD (CM)',38X,'EXPOSURE TIME (MIN)',//,
420       $2X,'THICKNESS (MM)',17X,'1',8X,'2',8X,'3',8X,'4',8X,'5',
430       $7X,'6',8X,'7',8X,'8',8X,'9',8X,'10',//)
440        IF(RADSO-2.) 21,22,23
450 C
460 C      EXPOSURE TIME CALCULATIONS FOR COBALT-60
470 C
```

```
480 21     MEV(1)=1.1731-1
490        MEV(2)=1.3324-1
500        MUM(1)=0.0551
510        MUM(2)=0.0516
520        A(1)=1
530        A(2)=1
540        DO 30 I=M,N
550        DO 24 J=3,12
560        TKMA=I
570        EQU=EXP(0.2111*J-1.6413)
580        TKMA2=TKMA*EQU
590        IF(TKMA2.LT.30.OR.TKMA2.GT.200.) GO TO 25
600        GO TO 26
610 25     EXPSR(J)=0.
620        GO TO 24
630 26     SFD=TKMA
640        FF=14.
650        IF(TKMA2.GT.80.) FF=13.
660        IF(TKMA2.GT.100.) FF=12.
670        IF(TKMA.LT.75.) SFD=75.
680        EXCO1=EXP((TKMA2+28.24)/33.5)
690        ETCO1=(EXCO1*60*SFD**2*F*FDSFA*0.77)/(SOACT*100**2)
700        EXCO2=EXP(0.03*TKMA2-0.72)
710        ETCO2=(EXCO2*60*SFD**2*F*FDSFA)/(SOACT*50**2)
720        EXCO3=EXP(0.031*TKMA2-1.82)
730        ETCO3=(EXCO3*60*SFD**2*F*FDSFA)/(SOACT*30**2)
740        CALL BUILD(BU,  ,BLDUP,MUM,MEV,2,TKMA2,DENMA,K1,L1,A)
750        ETCO4=10**9*FF*F*FDSFA*SFD**2*((EXP(VUCO1*TKMA2/10)/BLDU
760       X(1))+(EXP(VUCO2*TKMA2/10)/BLDUP(2)))/(SOACT*3.7*10**10*6
770        ETCO5=10**9*FF*F*FDSFA*SFD**2*(EXP(VUCO*DENMA*TKMA2/10.)
780       X(SOACT*3.7*10**10*60)
790        EXPSR(J)=ETCO4
800 24     CONTINUE
810        WRITE(6,210) TKMA,SFD,(EXPSR(J),J=3,12)
820 210    FORMAT(F11.1,F14.0,10F9.1)
830 30     CONTINUE
840        GO TO 61
850 C
```

```
860 C      EXPOSURE TIME CALCULATIONS FOR CESIUM 137
870 C
880 22     MUM(1)=0.0732
890        MEV(1)=0.662-0.5
900        A(1)=0.5
910        DO 40 I=M,N
920        DO 41 J=1,10
930        TKMA=I
940        EQU=EXP(EXP(0.1173*J-0.0910))/10.
950        TKMA2=TKMA*EQU
960        IF(TKMA2.LT.15.OR.TKMA2.GT.100.) GO TO 42
970        GO TO 43
980 42     EXPSR(J)=0.
990        GO TO 41
1000 43     SFD=TKMA
1010        IF(TKMA.LT.50.) SFD=50.
1020        EXCS1=EXP((TKMA2+48.92)/26.12)
1030        ETCS1=(EXCS1*60*SFD**2*F*FDSFA*0.77)/(SOACT*100**2)
1040        EXCS2=EXP(0.04*TKMA2-0.38)
1050        ETCS2=(EXCS2*60*SFD**2*F*FDSFA)/(SOACT*50**2)
1060        EXCS3=EXP(0.0285*TKMA2-1.489)/0.73
1070        ETCS3=(EXCS3*60*SDF**2*F*FDSFA)/(SOACT*30**2)
1080        CALL BUILD(BU,BLDUP,MUM,MEV,1,TKMA2,DENMA,K1,L1,A)
1090        ETCS4=10**9*FF*F*FDSFA*SFD**2*(EXP(VUCS*TKMA2/10.)/BLDUP
1100       *(1))/(SOACT*3.7*10**10*60)
1110        ETCS5=10**9*FF*F*FDSFA*SFD**2*(EXP(VUCSS*DENMA*TKMA2/10.
1120       *(SOACT*3.7*10**10*60)
1130        EXPSR(J)=ETCS4
1140 41     CONTINUE
1150        WRITE(6,220) TKMA,SFD,(EXPSR(J),J=1.10)
1160 220    FORMAT(F11.1,F14.0,10F9.1)
1170 40     CONTINUE
1180        GO TO 61
1190 C      EXPOSURE TIME CALCULATIONS FOR IRIDIUM 192
1200 C
1210 23     A(1)=0.2
1220        MUM(1)=0.0940
1230        MEV(1)=0.385-0.3
```

```
1240        DO 60 I=M,N
1250        DO 62 J=1,10
1260        TKMA=I
1270        EQU=EXP(EXP(0.1213*J-0.1109))/10.
1280        TKMA2=TKMA*EQU
1290        IF(TKMA2.LT.10.OR.TKMA2.GT.100.) GO TO 63
1300        GO TO 64
1310 63     EXPSR(J)=0.
1320        GO TO 62
1330 64     SFD=TKMA
1340        IF(TKMA.LT.50.) SFD=50.
1350        EXIR1=EXP((TKMA2+26.35)/19.21)
1360        ETIR1=(EXIR1*60*SFD**2*F*FDSFA*0.77)/(SOACT*100**2)
1370        EXIR2=EXP(0.047*TKMA2-0.236)
1380        ETIR2=(EXIR2*60*SFD**2*F*FDSFA)/(SOACT*50**2)
1390        EXIR3=EXP(0.044*TKMA2-0.964)
1400        ETIR3=(EXIR3*60*SFD**2*F*FDSFA)/(SOACT*30**2)
1410        CALL BUILD(BU,BLDUP,MUM,MEV,1,TKMA2,DENMA,K1,L1,A)
1420        ETIR4=10**9*FF*F*FDSFA*SFD**2*(EXP(VUIRR*TKMA2/10.)/BLDU
1430       &(1))/(SOACT*3.7*10**10*60)
1440        ETIR5=10**9*FF*F*FDSFA*SFD**2*(EXP(VUIR*DENMA*TKMA2/10.)
1450       &(SOACT*3.7*10**10*60)
1460        EXPSR(J)=ETIR4
1470 62     CONTINUE
1480        WRITE(6,230) TKMA,SFD,(EXPSR(J),J=1,10)
1490 230    FORMAT (F11.1,F14.0,10F9.1)
1500 60     CONTINUE
1510 61     STOP
1520        END
1530 C
1540 C      SUBROUTINE PROGRAMME FOR CALCULATIONS OF THE
1550 C      BUILD-UP FACTOR BY THE METHOD OF EXTRAPOLATION
1560 C
1570        SUBROUTINE BUILD (BU,BLDUP,MUM,MEV,KENGY,TKMA2,DENMA,K,
1580        REAL BLDUP(KENGY),MUM(KENGY),BU(5,8),DBU2(5),MEV(KENGY)
1590       &A(KENGY)
1600        DO 50 ICO=1,KENGY
1610        VUX=MUM(ICO)*TKMA2*DENMA/10
```

```
1620          DO 51 J=2,8
1630          IF(BU(1,J).GT.VUX) GO TO 53
1640 51       CONTINUE
1650 53       J1=J-1
1660          J2=J
1670          DMUX=BU(1.J2)-BU(1-J1)
1680          DMUX1=VUX-BU(1,J1)
1690          IF(ICO.LT.3) GO TO  54
1700          K=3
1710          L=4
1720 54       DO 52 I=K,L
1730          DBU=BU(I,J2)-BU(I,J1)
1740          DBU1=DBU*DMUX1/DMUX
1750          DBU2(I)=BU(I,J1)+DBU1
1760 52       CONTINUE
1770          DBU3=DBU2(K)-DBU2(L)
1780          DBU4=DBU3*MEV(ICO)/A(ICO)
1790          BLDUP(ICO)=DBU2(K)-DBU4
1800 50       CONTINUE
1810          RETURN
1820          END
@FTN,C TPF$.NAME$
FIN 8R1  *04/25/84 12:40(0,)
END FIN 798 IBANK 578 DBANK

   ENTERING USER PROGRAM
```

APPENDIX II

Exposure charts

utilized in this study

Film type : Industrex A (with lead screens)

Film density : 2.50

Source-to-film distance : 100 cm

Film development : standard processing

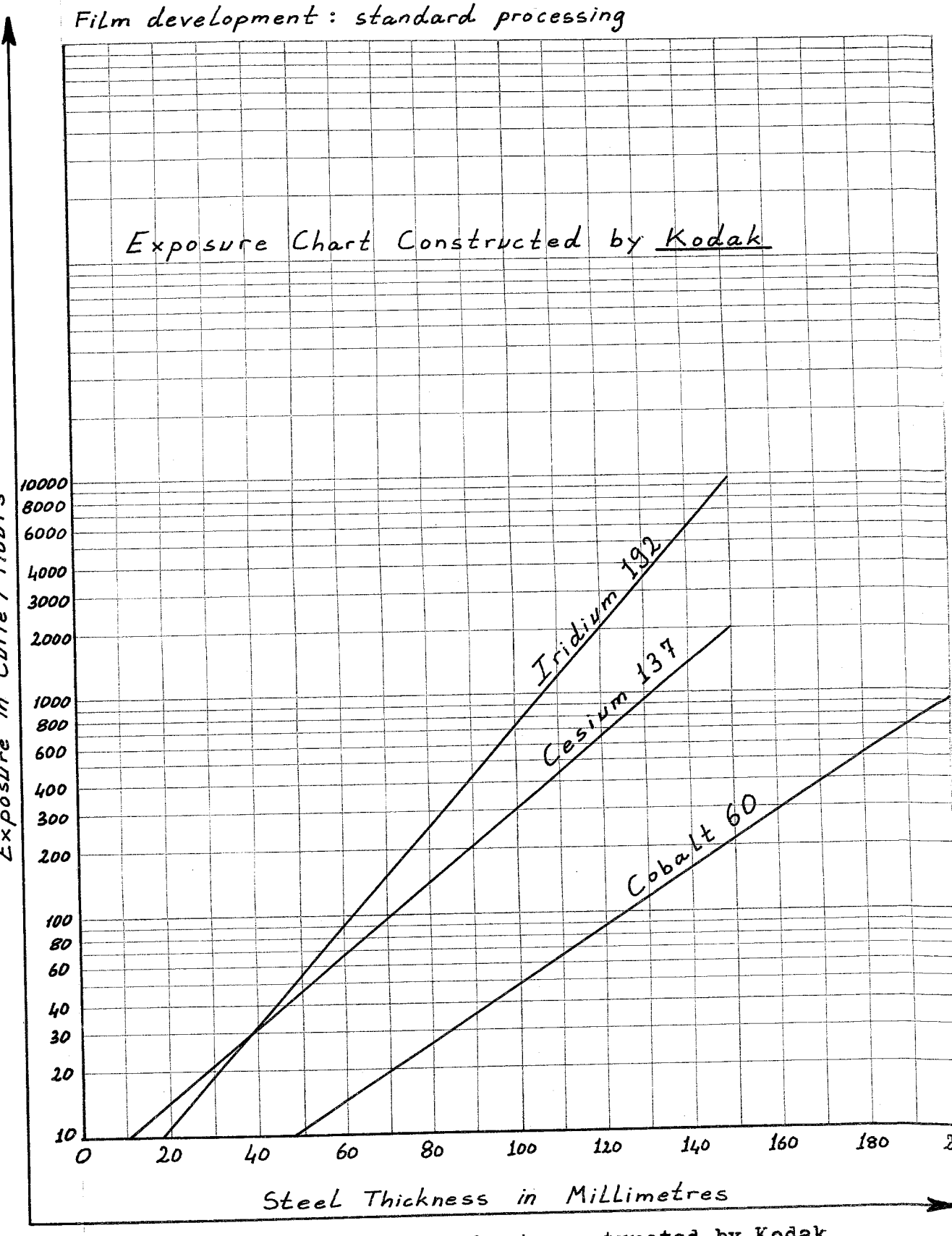


Table II-1 Exposure chart constructed by Kodak

Film type : structurix D7 (with lead screens)

Film density : 2.0

Source-to-film distance : 50 cm

Film development : standard processing

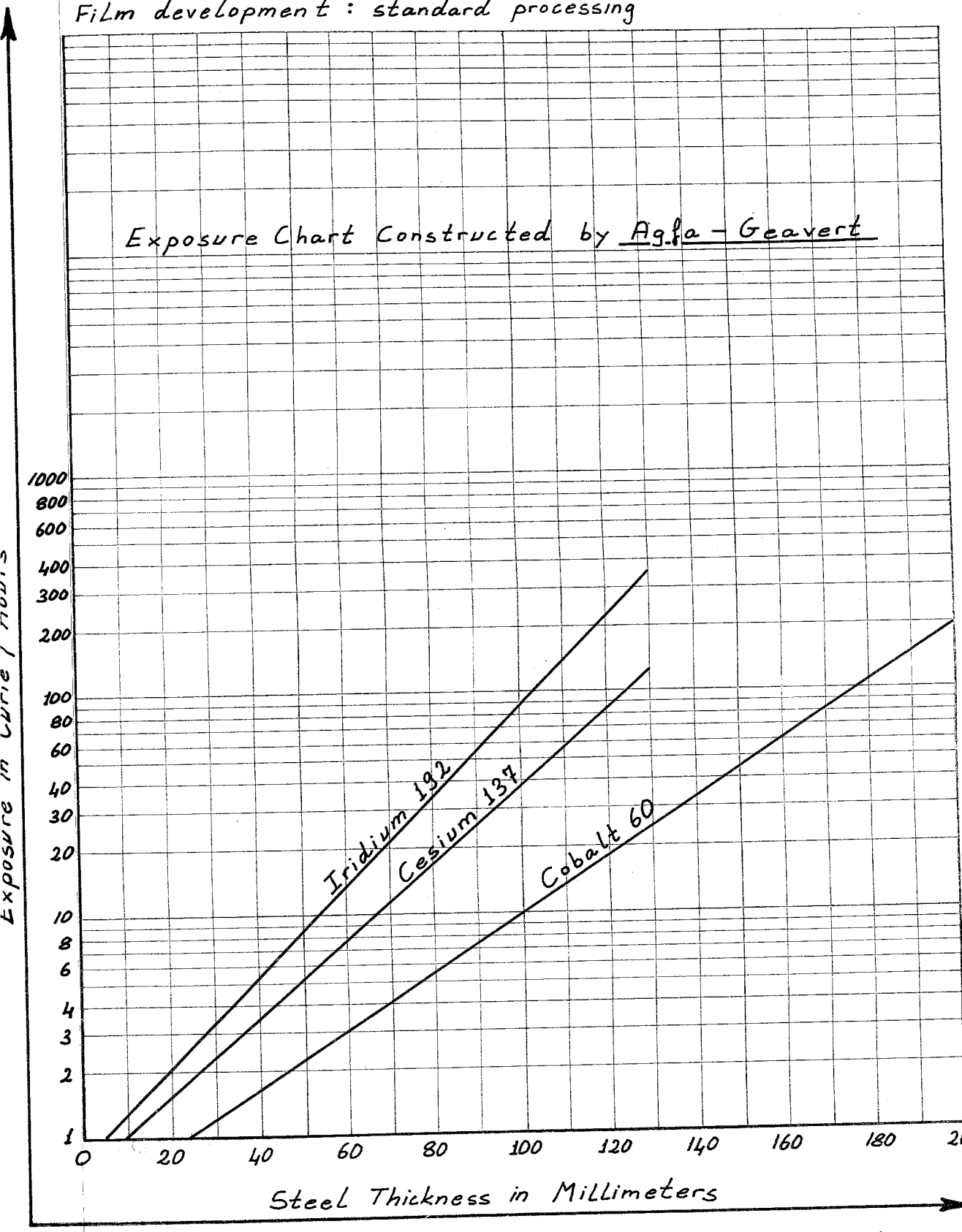


Table II-2 Exposure chart constructed by Agfa-Geavert

Film type: structurix D7 (with lead screens)

Film density: 2.0

Source-to-film distance: 30 cm

Film development: standard processing

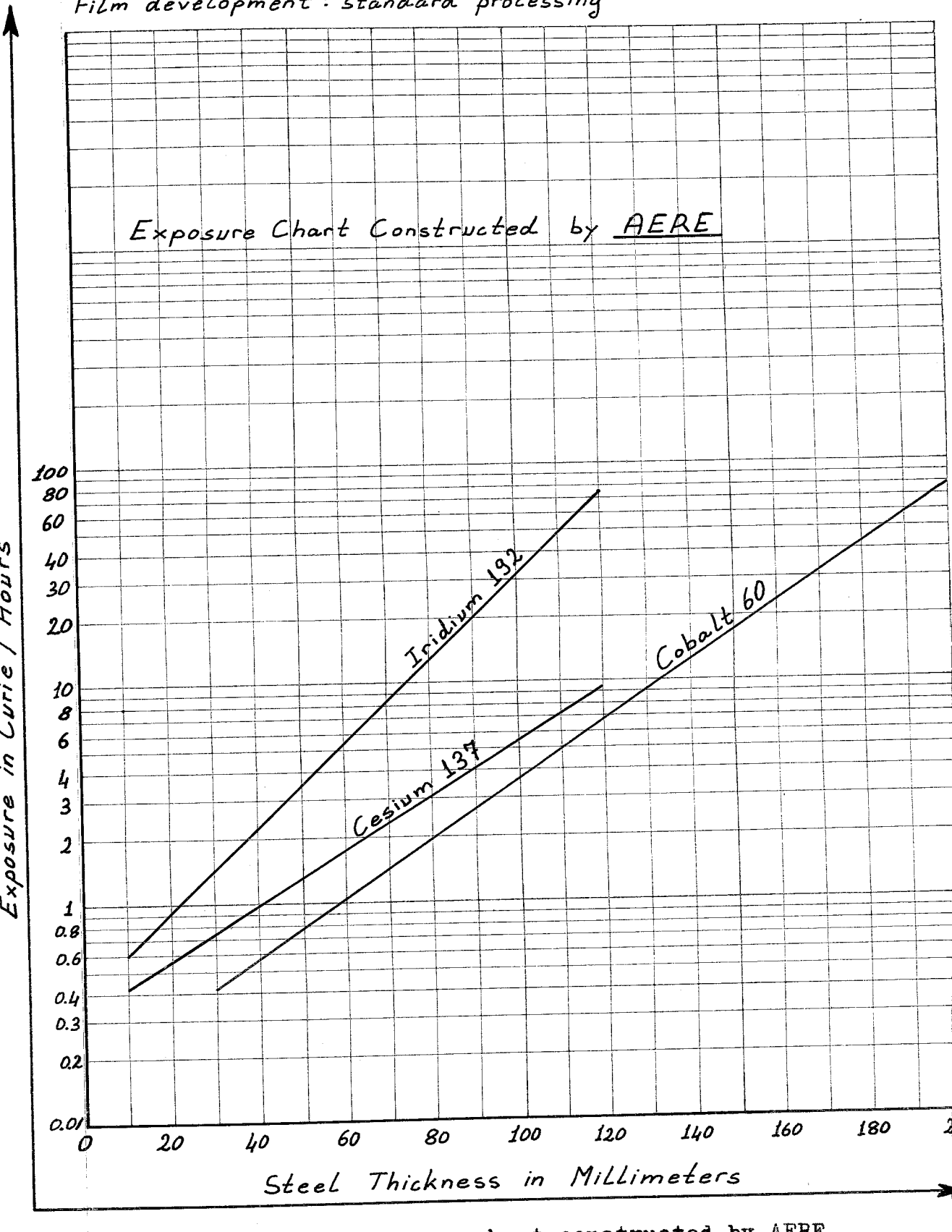
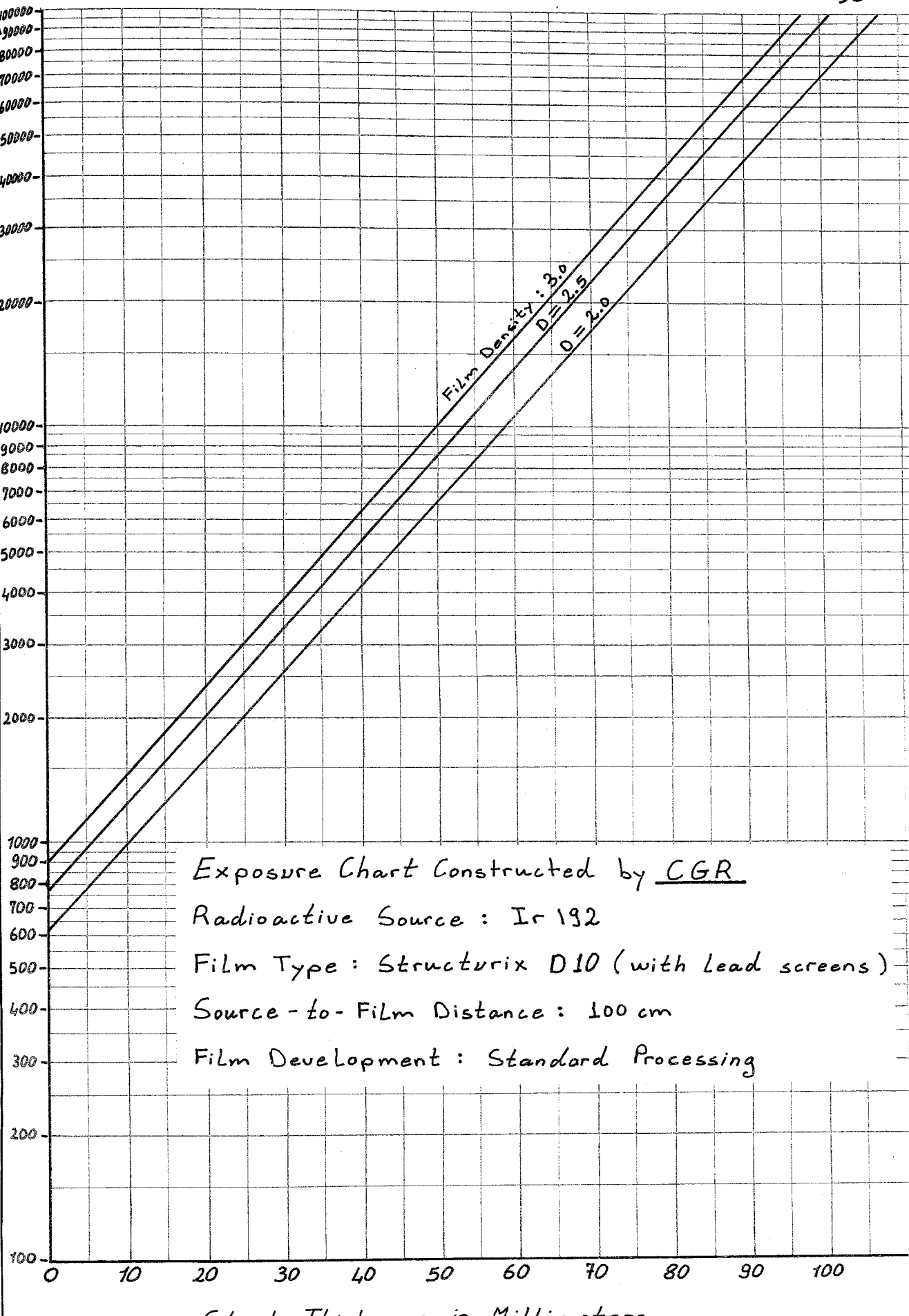


Table II-3 Exposure chart constructed by AERE



Exposure Chart Constructed by CGR

Radioactive Source : Ir 192

Film Type : Structurix D10 (with Lead screens)

Source-to-Film Distance : 100 cm

Film Development : Standard Processing

APPENDIX III

The least squares method

APPENDIX III

The Least Squares Method[16]

In many disciplines it is desirable to express one variable in terms of another even though the variables are independent and are not necessarily analytical functions of each other. An accepted practice is to perform a least-squares linear regression which is designed to minimize the sum of the squares of the deviations of the actual data points from the straight line of best fit. In practice, a plot of the variables (called a scatter diagram) is essentially constructe and the best straight line which uniformly divides the data points, is drawn as shown below (Fig. III-1). Because the data may not be best represented by a straight-line curve, it is desirable to measure how well the linear curve actually does fit the data. This measure is called the correlation coefficient and may be calculated from the independent variables and the linear equation parameters.

The linear curve is in the form of $y = mx + b$ where, m is the slope of the curve and denoted as,

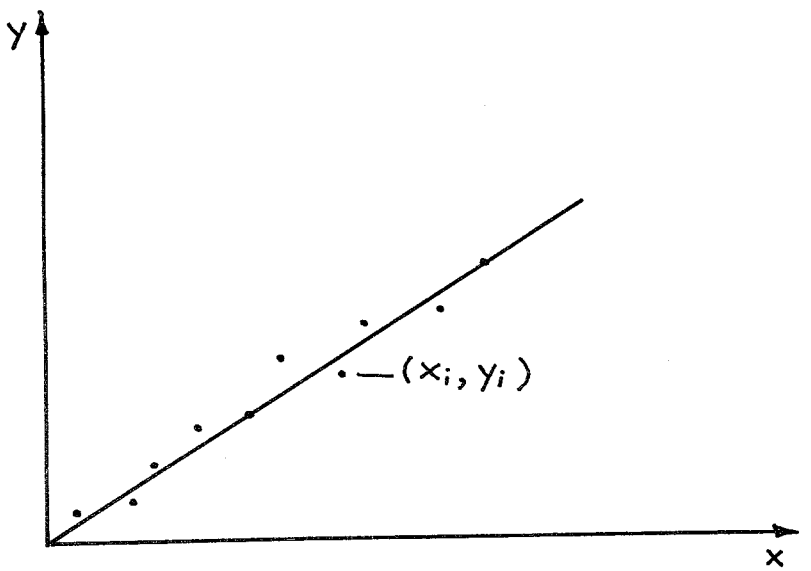


FIG. III-1 Scatter diagram.

$$m = \frac{\frac{\sum x_i \sum y_i}{N} - \sum x_i y_i}{\frac{(\sum x_i)^2}{N} - \sum x_i^2}$$

b is the y intercept of the curve and denoted as

$$b = \bar{y} - m\bar{x}$$

$$\bar{x} = \text{average x value} = \frac{\sum_{i=1}^{N} x_i}{N}$$

$$\bar{y} = \text{average y value} = \frac{\sum_{i=1}^{N} y_i}{N}$$

After the linear regression curve is determined, the degree of association between the random variables (x_i, y_i)_____(x_n, y_n) can be measured. This correlation coefficient is usually denoted by r and is calculated using the following expression,

$$r = \frac{m \sigma_x}{\sigma_y}$$

where:

$$\sigma_x^2 = \text{variance of the x values} = \frac{\sum_{i=1}^{N} x_i^2}{N} - \bar{x}^2$$

$$\sigma_y^2 = \text{variance of the y values} = \frac{\sum_{i=1}^{N} y_i^2}{N} - \bar{y}^2$$

The correlation coefficient value must be between ∓ 1 with ∓ 1 being a perfect correlation. The correlation coefficient value of the constructed exposure curves are between 0.980 - 1 and meet the required restrictions mentioned above.

APPENDIX IV

Constructed exposure tables by using several ETD methods

Table IV-1

Exposure Table for Cobalt 60

RADIOACTIVE SOURCE : COBALT 60
R. SOURCE ACTIVITY : 30.0 CURIE
MATERIAL : STEEL
FILM TYPE : STRUCTURIX D7
FILM DENSITY : 2

MATERIAL THICKNESS (MM)	SED (CM)	EXPOSURE TIME (MIN) KODAK	GEVAERT	Q.T.	ALTERN.	THEORE.
40.0	75.	6.7	7.4	7.1	5.2	3.6
41.0	75.	6.9	7.6	7.3	5.3	3.7
42.0	75.	7.1	7.8	7.5	5.5	3.8
43.0	75.	7.4	8.1	7.8	5.6	3.9
44.0	75.	7.6	8.3	8.0	5.8	4.0
45.0	75.	7.8	8.6	8.3	5.9	4.1
46.0	75.	8.0	8.8	8.5	6.1	4.2
47.0	75.	8.3	9.1	8.8	6.2	4.4
48.0	75.	8.5	9.4	9.1	6.4	4.5
49.0	75.	8.8	9.6	9.4	6.6	4.6
50.0	75.	9.1	9.9	9.7	6.8	4.7
51.0	75.	9.3	10.2	10.0	6.9	4.9
52.0	75.	9.6	10.5	10.3	7.1	5.0
53.0	75.	9.9	10.9	10.6	7.3	5.1
54.0	75.	10.2	11.2	10.9	7.5	5.3
55.0	75.	10.5	11.5	11.3	7.7	5.4
56.0	75.	10.8	11.9	11.6	7.9	5.6
57.0	75.	11.2	12.3	12.0	8.1	5.7
58.0	75.	11.5	12.6	12.4	8.3	5.9
59.0	75.	11.9	13.0	12.8	8.6	6.1
60.0	75.	12.2	13.4	13.2	8.8	6.2
61.0	75.	12.6	13.8	13.6	9.0	6.4
62.0	75.	13.0	14.2	14.0	9.3	6.6
63.0	75.	13.4	14.7	14.4	9.6	6.8
64.0	75.	13.8	15.1	14.9	9.8	7.0
65.0	75.	14.2	15.6	15.4	10.1	7.2
66.0	75.	14.6	16.1	15.9	10.4	7.4
67.0	75.	15.0	16.5	16.4	10.7	7.6
68.0	75.	15.5	17.0	16.9	11.0	7.8
69.0	75.	16.0	17.6	17.4	11.4	8.0
70.0	75.	16.5	18.1	18.0	11.7	8.2
71.0	75.	17.0	18.7	18.5	12.1	8.4
72.0	75.	17.5	19.2	19.1	12.4	8.7
73.0	75.	18.0	19.8	19.7	12.8	8.9
74.0	75.	18.5	20.4	20.3	13.2	9.2
75.0	75.	19.1	21.0	21.0	13.6	9.4
76.0	76.	20.2	22.3	22.2	14.4	9.9
77.0	77.	21.4	23.5	23.5	15.2	10.5
78.0	78.	22.6	24.9	24.9	16.1	11.1
79.0	79.	23.9	26.3	26.3	17.0	11.7

Table IV-1 (Continued)

MATERIAL THICKNESS (MM)	SED (CM)	EXPOSURE TIME (MIN) KODAK	GEVAERT	Q.T.	ALTERN.	THEORE.
80.0	80.	25.2	27.8	27.8	18.0	12.3
81.0	81.	26.7	29.4	29.4	17.7	12.0
82.0	82.	28.2	31.0	31.1	18.7	12.7
83.0	83.	29.7	32.7	32.9	19.8	13.3
84.0	84.	31.4	34.6	34.8	20.9	14.1
85.0	85.	33.1	36.5	36.7	22.1	14.8
86.0	86.	34.9	38.5	38.8	23.3	15.6
87.0	87.	36.8	40.6	40.9	24.6	16.4
88.0	88.	38.8	42.8	43.2	26.0	17.2
89.0	89.	40.9	45.1	45.6	27.5	18.1
90.0	90.	43.1	47.5	48.1	29.0	19.0
91.0	91.	45.4	50.0	50.7	30.6	20.0
92.0	92.	47.8	52.7	53.4	32.3	21.0
93.0	93.	50.3	55.0	56.3	34.1	22.1
94.0	94.	52.9	58.4	59.3	35.9	23.2
95.0	95.	55.7	61.5	62.5	37.9	24.3
96.0	96.	58.6	64.7	65.8	39.9	25.5
97.0	97.	61.6	68.1	69.3	42.0	26.8
98.0	98.	64.8	71.6	73.0	44.2	28.1
99.0	99.	68.2	75.3	76.9	46.6	29.5
100.0	100.	71.6	79.2	80.9	49.0	30.9
101.0	101.	75.3	83.2	85.1	47.6	29.9
102.0	102.	79.1	87.4	89.5	50.0	31.4
103.0	103.	83.1	91.9	94.2	52.6	32.9
104.0	104.	87.3	96.5	99.0	55.3	34.5
105.0	105.	91.7	101.4	104.1	58.2	36.1
106.0	106.	96.3	106.5	109.5	61.2	37.8
107.0	107.	101.1	111.8	115.0	64.3	39.6
108.0	108.	106.1	117.4	120.9	67.6	41.5
109.0	109.	111.4	123.2	127.0	71.1	43.5
110.0	110.	116.9	129.3	133.4	74.8	45.5
111.0	111.	122.6	135.7	140.2	78.6	47.6
112.0	112.	128.6	142.3	147.2	82.6	49.8
113.0	113.	134.9	149.3	154.5	86.8	52.1
114.0	114.	141.4	156.6	162.2	91.3	54.5
115.0	115.	148.3	164.2	170.3	95.9	57.0
116.0	116.	155.4	172.1	178.7	100.8	59.7
117.0	117.	162.9	180.4	187.5	105.9	62.4
118.0	118.	170.7	189.1	196.8	111.3	65.2
119.0	119.	178.9	198.2	206.4	116.9	68.2
120.0	120.	187.4	207.7	216.5	122.9	71.3
121.0	121.	196.3	217.6	227.1	129.1	74.5
122.0	122.	205.7	227.9	238.1	135.6	77.8
123.0	123.	215.4	238.7	249.6	142.5	81.3
124.0	124.	225.5	250.0	261.7	149.7	85.0
125.0	125.	236.1	261.8	274.3	157.2	88.7
126.0	126.	247.2	274.1	287.5	165.1	92.7
127.0	127.	258.7	287.0	301.3	173.4	96.8
128.0	128.	270.8	300.4	315.7	182.2	101.1
129.0	129.	283.4	314.4	330.7	191.3	105.5
130.0	130.	296.5	329.0	346.5	200.9	110.1
131.0	131.	310.2	344.3	362.9	211.0	115.0

Table IV-1 (Continued)

MATERIAL THICKNESS (MM)	SED (CM)	EXPOSURE TIME (MIN)				
		KODAK	GEVAERT	Q.T.	ALTERN.	THEORE.
132.0	132.	324.5	360.2	380.0	221.6	120.0
133.0	133.	339.4	376.8	398.0	232.7	125.2
134.0	134.	355.0	394.1	416.7	244.3	130.6
135.0	135.	371.2	412.2	436.3	256.5	136.3
136.0	136.	388.1	431.1	456.7	269.3	142.2
137.0	137.	405.8	450.8	478.0	282.7	148.3
138.0	138.	424.2	471.3	500.3	296.8	154.7
139.0	139.	443.4	492.7	523.5	311.6	161.3
140.0	140.	463.5	515.1	547.8	327.1	168.2
141.0	141.	484.4	538.4	573.2	343.4	175.4
142.0	142.	506.1	562.7	599.6	360.4	182.8
143.0	143.	528.8	588.0	627.3	378.3	190.6
144.0	144.	552.5	614.4	656.1	397.1	198.6
145.0	145.	577.2	641.9	686.2	416.8	207.0
146.0	146.	602.9	670.6	717.6	437.4	215.7
147.0	147.	629.7	700.6	750.4	459.0	224.8
148.0	148.	657.7	731.8	784.5	481.7	234.2
149.0	149.	686.8	764.3	820.2	505.5	244.0
150.0	150.	717.1	798.2	857.4	530.5	254.2

Table IV-2

Exposure Table for Cesium 137

RADIOACTIVE SOURCE : CESIUM 137
R. SOURCE ACTIVITY : 30.0 CURIE
MATERIAL : STEEL
FILM TYPE : STRUCTURIX D7
FILM DENSITY : 2

MATERIAL THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN) KODAK	GEVAERT	Q.T.	ALTERN.	THEORE.
20.0	50.	5.5	3.1	3.1	2.5	3.2
21.0	50.	5.7	3.2	3.2	2.6	3.3
22.0	50.	5.9	3.3	3.3	2.7	3.5
23.0	50.	6.1	3.5	3.3	2.7	3.6
24.0	50.	6.4	3.6	3.4	2.8	3.7
25.0	50.	6.6	3.8	3.5	2.9	3.8
26.0	50.	6.9	3.9	3.6	3.0	3.9
27.0	50.	7.1	4.1	3.8	3.1	4.1
28.0	50.	7.4	4.2	3.9	3.2	4.2
29.0	50.	7.7	4.4	4.0	3.3	4.4
30.0	50.	8.0	4.6	4.1	3.4	4.5
31.0	50.	8.3	4.8	4.2	3.6	4.7
32.0	50.	8.6	5.0	4.3	3.7	4.8
33.0	50.	9.0	5.2	4.5	3.8	5.0
34.0	50.	9.3	5.4	4.6	4.0	5.1
35.0	50.	9.7	5.6	4.7	4.1	5.3
36.0	50.	10.1	5.8	4.8	4.2	5.5
37.0	50.	10.5	6.1	5.0	4.4	5.7
38.0	50.	10.9	6.3	5.1	4.5	5.9
39.0	50.	11.3	6.6	5.3	4.7	6.1
40.0	50.	11.7	6.9	5.4	4.8	6.3
41.0	50.	12.2	7.1	5.6	5.0	6.5
42.0	50.	12.7	7.4	5.8	5.2	6.7
43.0	50.	13.2	7.7	5.9	5.4	6.9
44.0	50.	13.7	8.0	6.1	5.6	7.1
45.0	50.	14.2	8.4	6.3	5.8	7.4
46.0	50.	14.8	8.7	6.4	6.0	7.6
47.0	50.	15.3	9.1	6.6	6.2	7.9
48.0	50.	15.9	9.4	6.8	6.5	8.2
49.0	50.	16.5	9.8	7.0	6.7	8.4
50.0	50.	17.2	10.2	7.2	7.0	8.7
51.0	51.	18.6	11.1	7.7	7.6	9.4
52.0	52.	20.1	12.0	8.3	8.2	10.1
53.0	53.	21.7	13.0	8.8	8.8	10.8
54.0	54.	23.4	14.0	9.4	9.5	11.6
55.0	55.	25.2	15.1	10.1	10.3	12.4
56.0	56.	27.1	16.3	10.8	11.1	13.3
57.0	57.	29.2	17.6	11.5	12.0	14.3
58.0	58.	31.4	19.0	12.2	13.0	15.3
59.0	59.	33.8	20.4	13.0	14.0	16.3

Table IV-2 (Continued)

MATERIAL THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN) KODAK	GEVAERT	Q.T.	ALTERN.	THEORE.
60.0	60.	36.3	22.0	13.8	15.1	17.4
61.0	61.	39.0	23.6	14.7	16.2	18.6
62.0	62.	41.9	25.4	15.6	17.5	19.9
63.0	63.	44.9	27.3	16.6	18.8	21.2
64.0	64.	48.1	29.3	17.6	20.3	22.7
65.0	65.	51.6	31.5	18.7	21.8	24.1
66.0	66.	55.3	33.8	19.9	23.5	25.7
67.0	67.	59.2	36.2	21.1	25.3	27.4
68.0	68.	63.3	38.9	22.3	27.2	29.2
69.0	69.	67.8	41.6	23.6	29.3	31.1
70.0	70.	72.5	44.6	25.0	31.4	33.0
71.0	71.	77.5	47.8	26.5	33.6	35.1
72.0	72.	82.8	51.1	28.0	36.0	37.3
73.0	73.	88.4	54.7	29.7	38.5	39.7
74.0	74.	94.4	58.5	31.4	41.2	42.1
75.0	75.	100.7	62.6	33.1	44.1	44.7
76.0	76.	107.5	66.9	35.0	47.2	47.5
77.0	77.	114.6	71.4	37.0	50.5	50.4
78.0	78.	122.2	76.3	39.0	54.1	53.4
79.0	79.	130.3	81.4	41.2	57.8	56.6
80.0	80.	138.8	86.9	43.5	61.9	60.0
81.0	81.	147.9	92.8	45.9	66.2	63.6
82.0	82.	157.4	98.9	48.4	70.8	67.4
83.0	83.	167.6	105.5	51.0	75.7	71.3
84.0	84.	178.4	112.5	53.7	81.0	75.5
85.0	85.	189.8	119.9	56.6	86.6	79.9
86.0	86.	201.8	127.7	59.6	92.6	84.6
87.0	87.	214.6	136.0	62.8	99.0	89.4
88.0	88.	228.2	144.9	66.1	105.8	94.6
89.0	89.	242.5	154.2	69.6	113.1	100.0
90.0	90.	257.6	164.1	73.2	120.9	105.7
91.0	91.	273.7	174.6	77.0	129.2	111.7
92.0	92.	290.6	185.8	81.0	138.1	118.0
93.0	93.	308.6	197.6	85.1	147.6	124.6
94.0	94.	327.5	210.1	89.5	157.7	131.5
95.0	95.	347.6	223.4	94.0	168.5	138.9
96.0	96.	368.8	237.4	98.8	180.0	146.6
97.0	97.	391.2	252.3	103.8	192.3	154.7
98.0	98.	414.9	268.0	109.0	205.5	163.2
99.0	99.	440.0	284.7	114.4	219.5	172.1
100.0	100.	466.4	302.3	120.1	234.4	181.5

Table IV-3
Exposure Table for Iridium 192

RADIOACTIVE SOURCE : IRIDIUM 192
R. SOURCE ACTIVITY : 30.0 CURIE
MATERIAL : STEEL
FILM TYPE : STRUCTURIX D7
FILM DENSITY : 2

MATERIAL THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN) KODAK	GEVAERT	Q.T.	ALTERN.	THEORE.	CGR
12.0	50.	2.9	2.8	3.6	2.0	2.4	2.2
13.0	50.	3.0	2.9	3.8	2.1	2.5	2.3
14.0	50.	3.2	3.1	4.0	2.2	2.6	2.5
15.0	50.	3.4	3.2	4.1	2.2	2.7	2.6
16.0	50.	3.5	3.4	4.3	2.3	2.8	2.7
17.0	50.	3.7	3.6	4.5	2.4	2.9	2.8
18.0	50.	3.9	3.7	4.7	2.5	3.0	3.0
19.0	50.	4.1	3.9	4.9	2.6	3.1	3.1
20.0	50.	4.4	4.1	5.2	2.7	3.2	3.3
21.0	50.	4.6	4.3	5.4	2.8	3.4	3.4
22.0	50.	4.8	4.5	5.6	3.0	3.5	3.6
23.0	50.	5.1	4.7	5.9	3.1	3.6	3.8
24.0	50.	5.4	4.9	6.2	3.2	3.8	3.9
25.0	50.	5.6	5.2	6.4	3.4	3.9	4.1
26.0	50.	5.9	5.4	6.7	3.5	4.0	4.3
27.0	50.	6.3	5.7	7.0	3.7	4.2	4.5
28.0	50.	6.6	6.0	7.4	3.9	4.3	4.8
29.0	50.	6.9	6.2	7.7	4.0	4.5	5.0
30.0	50.	7.3	6.5	8.0	4.2	4.7	5.2
31.0	50.	7.7	6.9	8.4	4.4	4.8	5.5
32.0	50.	8.1	7.2	8.8	4.6	5.0	5.8
33.0	50.	8.6	7.5	9.2	4.8	5.2	6.0
34.0	50.	9.0	7.9	9.6	5.0	5.4	6.3
35.0	50.	9.5	8.3	10.0	5.2	5.6	6.6
36.0	50.	10.0	8.7	10.5	5.5	5.8	7.0
37.0	50.	10.5	9.1	10.9	5.7	6.0	7.3
38.0	50.	11.1	9.5	11.4	6.0	6.2	7.6
39.0	50.	11.7	10.0	11.9	6.3	6.5	8.0
40.0	50.	12.3	10.5	12.5	6.6	6.7	8.4
41.0	50.	13.0	11.0	13.0	7.0	6.9	8.8
42.0	50.	13.7	11.5	13.6	7.3	7.2	9.2
43.0	50.	14.4	12.1	14.2	7.7	7.5	9.7
44.0	50.	15.2	12.6	14.9	8.1	7.7	10.2
45.0	50.	16.0	13.3	15.5	8.6	8.0	10.6
46.0	50.	16.8	13.9	16.2	9.0	8.3	11.2
47.0	50.	17.7	14.6	17.0	9.5	8.6	11.7
48.0	50.	18.7	15.3	17.7	10.1	8.9	12.3
49.0	50.	19.7	16.0	18.5	10.6	9.3	12.9
50.0	50.	20.7	16.8	19.4	11.2	9.6	13.5
51.0	51.	22.7	18.3	21.0	12.3	10.4	14.7

Table IV-3 (Continued)

MATERIAL THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN) KODAK	GEVAERT	Q.T.	ALTERN.	THEORE.	CGR
52.0	52.	24.9	19.9	22.9	13.5	11.2	16.0
53.0	53.	27.2	21.7	24.8	14.8	12.0	17.5
54.0	54.	29.8	23.6	26.9	16.3	13.0	19.0
55.0	55.	32.6	25.7	29.2	17.8	13.9	20.7
56.0	56.	35.5	27.9	31.6	19.4	15.0	22.5
57.0	57.	38.8	30.3	34.2	21.2	16.1	24.4
58.0	58.	42.3	32.8	37.0	23.1	17.3	26.5
59.0	59.	46.1	35.6	40.0	25.1	18.5	28.7
60.0	60.	50.3	38.6	43.3	27.4	19.9	31.2
61.0	61.	54.7	41.8	46.7	29.9	21.3	33.8
62.0	62.	59.5	45.3	50.4	32.6	22.8	36.6
63.0	63.	64.8	49.0	54.4	35.5	24.4	39.6
64.0	64.	70.4	53.0	58.7	38.7	26.1	42.8
65.0	65.	76.5	57.3	63.3	42.1	27.9	46.3
66.0	66.	83.1	62.0	68.2	45.9	29.9	50.1
67.0	67.	90.2	66.9	73.4	50.0	31.9	54.1
68.0	68.	97.9	72.2	79.0	54.5	34.1	58.4
69.0	69.	106.2	78.0	85.0	59.3	36.4	63.1
70.0	70.	115.1	84.1	91.4	64.6	38.8	68.1
71.0	71.	124.8	90.7	98.3	70.3	41.4	73.4
72.0	72.	135.2	97.7	105.6	76.6	44.2	79.2
73.0	73.	146.4	105.3	113.5	83.4	47.1	85.3
74.0	74.	158.4	113.4	121.9	90.7	50.1	91.9
75.0	75.	171.4	122.1	130.8	98.8	53.4	99.0
76.0	76.	185.5	131.4	140.4	107.5	56.9	106.6
77.0	77.	200.5	141.4	150.5	117.0	60.5	114.7
78.0	78.	216.8	152.1	161.4	127.3	64.4	123.4
79.0	79.	234.3	163.5	173.0	138.4	68.5	132.7
80.0	80.	253.1	175.8	185.4	150.6	72.8	142.7
81.0	81.	273.3	188.8	198.7	163.8	77.4	153.4
82.0	82.	295.0	202.9	212.8	178.2	82.2	164.8
83.0	83.	318.4	217.8	227.8	193.8	87.3	177.0
84.0	84.	343.6	233.8	243.8	210.7	92.8	190.1
85.0	85.	370.6	251.0	260.9	229.1	98.5	204.1
86.0	86.	399.6	269.3	279.0	249.1	104.5	219.0
87.0	87.	430.8	288.8	298.4	270.8	110.9	235.0
88.0	88.	464.4	309.7	319.1	294.4	117.6	252.1
89.0	89.	500.4	332.1	341.0	320.0	124.8	270.3
90.0	90.	539.0	355.9	364.4	347.7	132.3	289.8
91.0	91.	580.5	381.4	389.3	377.9	140.2	310.7
92.0	92.	625.0	408.5	415.8	410.7	148.6	332.9
93.0	93.	672.8	437.6	444.0	446.3	157.4	356.7
94.0	94.	724.1	468.5	474.0	484.9	166.7	382.0
95.0	95.	779.1	501.6	505.9	526.2	176.6	409.1
96.0	96.	838.1	536.9	539.9	569.5	187.0	438.0
97.0	97.	901.4	574.5	576.0	616.3	197.9	468.8
98.0	98.	969.2	614.6	614.4	667.0	209.4	501.7
99.0	99.	1042.0	657.4	655.2	721.9	221.6	536.8
100.0	100.	1119.9	703.0	698.6	781.3	234.4	574.3

APPENDIX V

Constructed exposure tables by using 'Alternative Method'

Table V- 1

Exposure Table for Cobalt 60

RADIOACTIVE SOURCE : COBALT 60
R. SOURCE ACTIVITY : 30.0 CURIE
MATERIAL : STEEL
FILM TYPE : STRUCTURIX D7
FILM DENSITY : 2

MATERIAL CKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)	THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)
40.0	75.	5.2	96.0	96.	39.9
41.0	75.	5.3	97.0	97.	42.0
42.0	75.	5.5	98.0	98.	44.2
43.0	75.	5.6	99.0	99.	46.6
44.0	75.	5.8	100.0	100.	49.0
45.0	75.	5.9	101.0	101.	47.6
46.0	75.	6.1	102.0	102.	50.0
47.0	75.	6.2	103.0	103.	52.6
48.0	75.	6.4	104.0	104.	55.3
49.0	75.	6.6	105.0	105.	58.2
50.0	75.	6.8	106.0	106.	61.2
51.0	75.	6.9	107.0	107.	64.3
52.0	75.	7.1	108.0	108.	67.6
53.0	75.	7.3	109.0	109.	71.1
54.0	75.	7.5	110.0	110.	74.8
55.0	75.	7.7	111.0	111.	78.6
56.0	75.	7.9	112.0	112.	82.6
57.0	75.	8.1	113.0	113.	86.8
58.0	75.	8.3	114.0	114.	91.3
59.0	75.	8.6	115.0	115.	95.9
60.0	75.	8.8	116.0	116.	100.8
61.0	75.	9.0	117.0	117.	105.9
62.0	75.	9.3	118.0	118.	111.3
63.0	75.	9.6	119.0	119.	116.9
64.0	75.	9.8	120.0	120.	122.9
65.0	75.	10.1	121.0	121.	129.1
66.0	75.	10.4	122.0	122.	135.6
67.0	75.	10.7	123.0	123.	142.5
68.0	75.	11.0	124.0	124.	149.7
69.0	75.	11.4	125.0	125.	157.2
70.0	75.	11.7	126.0	126.	165.1
71.0	75.	12.1	127.0	127.	173.4
72.0	75.	12.4	128.0	128.	182.2
73.0	75.	12.8	129.0	129.	191.3
74.0	75.	13.2	130.0	130.	200.9
75.0	75.	13.6	131.0	131.	211.0
76.0	76.	14.4	132.0	132.	221.6
77.0	77.	15.2	133.0	133.	232.7
78.0	78.	16.1	134.0	134.	244.3
79.0	79.	17.0	135.0	135.	256.5

Table V-1 (Continued)

MATERIAL CKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)	THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)
80.0	80.	18.0	136.0	136.	269.3
81.0	81.	17.7	137.0	137.	282.7
82.0	82.	18.7	138.0	138.	296.8
83.0	83.	19.8	139.0	139.	311.6
84.0	84.	20.9	140.0	140.	327.1
85.0	85.	22.1	141.0	141.	343.4
86.0	86.	23.3	142.0	142.	360.4
87.0	87.	24.6	143.0	143.	378.3
88.0	88.	26.0	144.0	144.	397.1
89.0	89.	27.5	145.0	145.	416.8
90.0	90.	29.0	146.0	146.	437.4
91.0	91.	30.6	147.0	147.	459.0
92.0	92.	32.3	148.0	148.	481.7
93.0	93.	34.1	149.0	149.	505.5
94.0	94.	35.9	150.0	150.	530.5
95.0	95.	37.9			

Table V-2

Exposure Table for Cesium 137

RADIOACTIVE SOURCE : CESIUM 137
R. SOURCE ACTIVITY : 30.0 CURIE
MATERIAL : STEEL
FILM TYPE : STRUCTURIX D7
FILM DENSITY : 2

MATERIAL ICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)	THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)
20.0	50.	2.5	61.0	61.	16.2
21.0	50.	2.6	62.0	62.	17.5
22.0	50.	2.7	63.0	63.	18.8
23.0	50.	2.7	64.0	64.	20.3
24.0	50.	2.8	65.0	65.	21.8
25.0	50.	2.9	66.0	66.	23.5
26.0	50.	3.0	67.0	67.	25.3
27.0	50.	3.1	68.0	68.	27.2
28.0	50.	3.2	69.0	69.	29.3
29.0	50.	3.3	70.0	70.	31.4
30.0	50.	3.4	71.0	71.	33.6
31.0	50.	3.6	72.0	72.	36.0
32.0	50.	3.7	73.0	73.	38.5
33.0	50.	3.8	74.0	74.	41.2
34.0	50.	4.0	75.0	75.	44.1
35.0	50.	4.1	76.0	76.	47.2
36.0	50.	4.2	77.0	77.	50.5
37.0	50.	4.4	78.0	78.	54.1
38.0	50.	4.5	79.0	79.	57.8
39.0	50.	4.7	80.0	80.	61.9
40.0	50.	4.8	81.0	81.	66.2
41.0	50.	5.0	82.0	82.	70.8
42.0	50.	5.2	83.0	83.	75.7
43.0	50.	5.4	84.0	84.	81.0
44.0	50.	5.6	85.0	85.	86.6
45.0	50.	5.8	86.0	86.	92.6
46.0	50.	6.0	87.0	87.	99.0
47.0	50.	6.2	88.0	88.	105.8
48.0	50.	6.5	89.0	89.	113.1
49.0	50.	6.7	90.0	90.	120.9
50.0	50.	7.0	91.0	91.	129.2
51.0	51.	7.6	92.0	92.	138.1
52.0	52.	8.2	93.0	93.	147.6
53.0	53.	8.8	94.0	94.	157.7
54.0	54.	9.5	95.0	95.	168.5
55.0	55.	10.3	96.0	96.	180.0
56.0	56.	11.1	97.0	97.	192.3
57.0	57.	12.0	98.0	98.	205.5
58.0	58.	13.0	99.0	99.	219.5
59.0	59.	14.0	100.0	100.	234.4
60.0	60.	15.1			

Table V-3

Exposure Table for Iridium 192

RADIOACTIVE SOURCE : IRIDIUM 192

R. SOURCE ACTIVITY : 30.0 CURIE

MATERIAL : STEEL

FILM TYPE : STRUCTURIX D7

FILM DENSITY : 2

MATERIAL ICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)	THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)
12.0	50.	2.0	57.0	57.	21.2
13.0	50.	2.1	58.0	58.	23.1
14.0	50.	2.2	59.0	59.	25.1
15.0	50.	2.2	60.0	60.	27.4
16.0	50.	2.3	61.0	61.	29.9
17.0	50.	2.4	62.0	62.	32.6
18.0	50.	2.5	63.0	63.	35.5
19.0	50.	2.6	64.0	64.	38.7
20.0	50.	2.7	65.0	65.	42.1
21.0	50.	2.8	66.0	66.	45.9
22.0	50.	3.0	67.0	67.	50.0
23.0	50.	3.1	68.0	68.	54.5
24.0	50.	3.2	69.0	69.	59.3
25.0	50.	3.4	70.0	70.	64.6
26.0	50.	3.5	71.0	71.	70.3
27.0	50.	3.7	72.0	72.	76.6
28.0	50.	3.9	73.0	73.	83.4
29.0	50.	4.0	74.0	74.	90.7
30.0	50.	4.2	75.0	75.	98.8
31.0	50.	4.4	76.0	76.	107.5
32.0	50.	4.6	77.0	77.	117.0
33.0	50.	4.8	78.0	78.	127.3
34.0	50.	5.0	79.0	79.	138.4
35.0	50.	5.2	80.0	80.	150.6
36.0	50.	5.5	81.0	81.	163.8
37.0	50.	5.7	82.0	82.	178.2
38.0	50.	6.0	83.0	83.	193.8
39.0	50.	6.3	84.0	84.	210.7
40.0	50.	6.6	85.0	85.	229.1
41.0	50.	7.0	86.0	86.	249.1
42.0	50.	7.3	87.0	87.	270.8
43.0	50.	7.7	88.0	88.	294.4
44.0	50.	8.1	89.0	89.	320.0
45.0	50.	8.6	90.0	90.	347.7
46.0	50.	9.0	91.0	91.	377.9
47.0	50.	9.5	92.0	92.	410.7
48.0	50.	10.1	93.0	93.	446.3
49.0	50.	10.6	94.0	94.	484.9
50.0	50.	11.2	95.0	95.	526.2
51.0	51.	12.3	96.0	96.	569.5
52.0	52.	13.5	97.0	97.	616.3
53.0	53.	14.8	98.0	98.	667.0
54.0	54.	16.3	99.0	99.	721.9
55.0	55.	17.8	100.0	100.	781.3
56.0	56.	19.4			

APPENDIX VI

Constructed exposure tables according to material densities by using 'Alternative Method'

Table VI-1

Exposure Table for Cobalt 60

According to Material Densities

from 3.0 gm/cm^3 to 7.0 gm/cm^3

RADIOACTIVE SOURCE : COBALT 60

R. SOURCE ACTIVITY : 30.0 CURIE

FILM TYPE : STRUCTURIX D7

FILM DENSITY : 2

TERIAL DENSITY (gm/cm^3)		3	4	5	6	7
MATERIAL ICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)				
40.0	75.	.0	.0	.0	.0	4.4
41.0	75.	.0	.0	.0	.0	4.5
42.0	75.	.0	.0	.0	.0	4.6
43.0	75.	.0	.0	.0	.0	4.7
44.0	75.	.0	.0	.0	4.1	4.8
45.0	75.	.0	.0	.0	4.1	4.9
46.0	75.	.0	.0	.0	4.2	5.1
47.0	75.	.0	.0	.0	4.3	5.2
48.0	75.	.0	.0	.0	4.3	5.3
49.0	75.	.0	.0	.0	4.4	5.4
50.0	75.	.0	.0	.0	4.5	5.5
51.0	75.	.0	.0	.0	4.6	5.7
52.0	75.	.0	.0	.0	4.6	5.8
53.0	75.	.0	.0	.0	4.7	5.9
54.0	75.	.0	.0	4.0	4.8	6.1
55.0	75.	.0	.0	4.1	4.9	6.2
56.0	75.	.0	.0	4.2	5.0	6.3
57.0	75.	.0	.0	4.2	5.1	6.5
58.0	75.	.0	.0	4.3	5.2	6.6
59.0	75.	.0	.0	4.3	5.3	6.8
60.0	75.	.0	.0	4.4	5.3	6.9
61.0	75.	.0	.0	4.4	5.4	7.1
62.0	75.	.0	.0	4.5	5.5	7.2
63.0	75.	.0	.0	4.6	5.7	7.4
64.0	75.	.0	.0	4.6	5.8	7.6
65.0	75.	.0	.0	4.7	5.9	7.7
66.0	75.	.0	.0	4.8	6.0	7.9
67.0	75.	.0	4.1	4.8	6.1	8.1
68.0	75.	.0	4.1	4.9	6.2	8.3
69.0	75.	.0	4.1	5.0	6.3	8.5
70.0	75.	.0	4.2	5.0	6.4	8.7
71.0	75.	.0	4.2	5.1	6.5	8.9
72.0	75.	.0	4.3	5.2	6.7	9.1
73.0	75.	.0	4.3	5.3	6.8	9.3
74.0	75.	.0	4.4	5.3	6.9	9.5
75.0	75.	.0	4.4	5.4	7.0	9.8
76.0	76.	.0	4.6	5.6	7.3	10.3
77.0	77.	.0	4.8	5.9	7.7	10.8
78.0	78.	.0	4.9	6.1	8.0	11.4

Table VI-1 (Continued)

TERIAL DENSITY (gm/cm^3)	3	4	5	6	7
MATERIAL	SFD (CM)	EXPOSURE TIME (MIN)			
ICKNESS (MM)					
79.0	79.	.0	5.1	6.4	8.4	11.9
80.0	80.	.0	5.3	6.6	8.7	12.5
81.0	81.	.0	5.5	6.9	9.1	13.2
82.0	82.	.0	5.7	7.2	9.5	13.9
83.0	83.	5.0	5.9	7.5	9.9	14.6
84.0	84.	5.1	6.1	7.8	10.4	15.3
85.0	85.	5.3	6.4	8.1	10.8	16.0
86.0	86.	5.5	6.6	8.4	11.3	16.9
87.0	87.	5.7	6.8	8.7	11.8	17.7
88.0	88.	5.8	7.1	9.1	12.3	18.6
89.0	89.	6.0	7.3	9.4	12.8	19.5
90.0	90.	6.2	7.6	9.7	13.4	20.4
91.0	91.	6.4	7.8	10.1	13.9	21.5
92.0	92.	6.6	8.1	10.5	14.5	22.5
93.0	93.	6.8	8.4	10.9	15.1	23.6
94.0	94.	7.0	8.7	11.3	15.7	24.7
95.0	95.	7.3	8.9	11.7	16.4	24.1
96.0	96.	7.5	9.3	12.1	17.1	25.3
97.0	97.	7.7	9.6	12.5	17.8	25.6
98.0	98.	7.9	9.9	13.0	18.5	27.8
99.0	99.	8.2	10.2	13.4	19.3	29.1
100.0	100.	8.4	10.5	13.9	20.1	30.5
101.0	101.	8.7	10.9	14.4	20.9	31.9
102.0	102.	8.9	11.2	14.9	21.7	33.5
103.0	103.	9.2	11.6	15.4	22.6	35.0
104.0	104.	9.4	12.0	16.0	23.5	36.7
105.0	105.	9.7	12.3	16.5	24.5	38.4
106.0	106.	10.0	12.7	17.1	25.5	40.3
107.0	107.	10.3	13.1	17.7	26.5	42.2
108.0	108.	10.6	13.5	18.3	27.6	44.1
109.0	109.	10.9	13.9	18.9	28.7	46.2
110.0	110.	11.2	14.4	19.6	29.8	48.3
111.0	111.	11.5	14.8	20.3	31.0	50.5
112.0	112.	11.8	15.2	21.0	32.2	52.8
113.0	113.	12.1	15.7	21.7	33.5	55.2
114.0	114.	12.5	16.2	22.4	34.8	57.6
115.0	115.	12.8	16.6	23.2	36.2	60.2
116.0	116.	13.2	17.1	23.9	37.6	63.0
117.0	117.	13.5	17.6	24.7	36.3	65.7
118.0	118.	13.9	18.1	25.6	37.7	63.3
119.0	119.	14.3	18.7	26.4	39.2	66.1
120.0	120.	14.7	19.2	27.3	40.7	69.0
121.0	121.	15.1	19.8	28.2	42.3	72.0
122.0	122.	15.5	20.3	29.2	43.9	75.2
123.0	123.	15.9	20.9	30.1	45.6	78.5
124.0	124.	16.3	21.5	31.1	47.4	81.9
125.0	125.	16.7	22.1	32.1	49.2	85.5
126.0	126.	17.2	22.8	33.2	51.1	89.2
127.0	127.	17.6	23.4	34.3	53.0	93.1
128.0	128.	18.0	24.1	35.4	55.1	97.1
129.0	129.	18.5	24.7	36.6	57.2	101.3

Table VI-1 (Continued)

TERIAL DENSITY (gm/cm^3)	3	4	5	6	7
MATERIAL	SFD (CM)	EXPOSURE TIME (MIN)			
ICKNESS (MM)					
130.0	130.	19.0	25.4	37.8	59.4	105.7
131.0	131.	19.5	26.2	39.0	61.6	110.3
132.0	132.	19.9	26.9	40.2	63.9	115.0
133.0	133.	20.4	27.6	41.5	66.4	120.0
134.0	134.	21.0	28.4	42.9	68.9	125.2
135.0	135.	21.5	29.2	44.3	71.4	130.6
136.0	136.	22.0	30.0	45.7	74.0	136.2
137.0	137.	22.5	30.8	47.2	76.8	142.1
138.0	138.	23.1	31.7	48.7	79.6	148.2
139.0	139.	23.6	37.6	50.2	82.5	154.6
140.0	140.	24.2	33.4	51.8	85.5	161.2
141.0	141.	24.8	34.4	53.5	88.6	168.1
142.0	142.	25.4	35.3	55.2	91.8	175.3
143.0	143.	26.0	36.3	56.9	95.1	182.8
144.0	144.	26.6	37.2	54.5	98.5	190.6
145.0	145.	27.2	38.3	56.2	102.0	198.8
146.0	146.	27.8	39.3	58.0	97.5	207.3
147.0	147.	28.5	40.4	59.8	101.0	216.1
148.0	148.	29.2	41.4	61.7	104.5	225.3
149.0	149.	29.8	42.6	63.6	108.2	234.9
150.0	150.	30.5	43.7	65.6	112.0	244.9

Table VI-2

Exposure Table for Cobalt 60

According to Material Densities

from 8.0 gm/cm^3 to 12.0 gm/cm^3

RADIOACTIVE SOURCE : COBALT 60

R. SOURCE ACTIVITY : 30.0 CURIE

FILM TYPE : STRUCTURIX D7

FILM DENSITY : 2

ATERIAL DENSITY (gm/cm^3)		8	9	10	11	12
MATERIAL ICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)				
40.0	75.	5.4	7.1	9.8	15.4	25.6
41.0	75.	5.6	7.3	10.3	15.2	25.5
42.0	75.	5.8	7.6	10.8	16.1	27.4
43.0	75.	5.9	7.8	11.3	17.2	29.6
44.0	75.	6.1	8.1	11.8	18.3	32.0
45.0	75.	6.3	8.4	12.4	19.5	34.5
46.0	75.	6.4	8.7	13.0	20.7	37.3
47.0	75.	6.6	9.0	13.7	22.1	40.4
48.0	75.	6.8	9.3	14.4	23.5	43.7
49.0	75.	7.0	9.7	15.1	25.0	47.3
50.0	75.	7.2	10.1	15.8	26.5	51.2
51.0	75.	7.4	10.4	15.4	26.0	55.5
52.0	75.	7.6	10.8	16.2	27.7	60.2
53.0	75.	7.8	11.3	17.1	29.4	65.3
54.0	75.	8.0	11.7	18.0	31.3	70.9
55.0	75.	8.3	12.1	18.9	33.3	77.0
56.0	75.	8.5	12.6	19.9	35.5	83.7
57.0	75.	8.7	13.1	20.9	37.8	90.9
58.0	75.	9.0	13.6	22.0	40.2	98.9
59.0	75.	9.3	14.2	23.1	42.9	107.5
60.0	75.	9.5	14.8	24.3	45.7	117.0
61.0	75.	9.8	15.4	25.6	48.8	127.3
62.0	75.	10.1	14.8	26.9	52.1	138.6
63.0	75.	10.4	15.5	26.0	55.6	150.9
64.0	75.	10.8	16.1	27.4	59.4	164.4
65.0	75.	11.1	16.8	28.8	63.4	179.2
66.0	75.	11.4	17.5	30.2	67.7	195.3
67.0	75.	11.8	18.2	31.8	72.4	212.6
68.0	75.	12.2	18.9	33.4	77.4	231.4
69.0	75.	12.6	19.7	35.2	82.8	251.9
70.0	75.	13.0	20.6	37.0	88.5	274.3
71.0	75.	13.4	21.5	39.0	94.7	298.7
72.0	75.	13.8	22.3	41.0	101.4	325.0
73.0	75.	14.3	23.3	43.2	108.5	353.8
74.0	75.	14.7	24.2	45.5	116.2	385.2
75.0	75.	15.2	25.2	47.9	124.4	419.6
76.0	76.	16.1	27.0	51.9	136.8	469.5
77.0	77.	15.9	28.8	56.1	150.5	525.2
78.0	78.	16.8	28.4	60.7	165.5	587.5

Table VI-2 (Continued)

TERIAL DENSITY (gm/cm^3)	8	9	10	11	12
MATERIAL	SFD (CM)	EXPOSURE TIME (MIN)			
ICKNESS (MM)					
79.0	79.	17.8	30.3	65.7	181.9	657.2
80.0	80.	18.9	32.4	71.1	200.0	735.1
81.0	81.	20.0	34.5	76.9	219.8	822.3
82.0	82.	21.2	36.8	83.1	241.5	.0
83.0	83.	22.5	39.3	89.9	264.9	.0
84.0	84.	23.8	42.0	97.2	290.6	.0
85.0	85.	25.2	44.8	105.0	318.8	.0
86.0	86.	26.7	47.8	113.6	349.6	.0
87.0	87.	28.2	50.9	122.7	383.4	.0
88.0	88.	29.9	54.3	132.6	420.1	.0
89.0	89.	31.5	57.9	143.3	460.2	.0
90.0	90.	33.3	61.8	154.9	504.0	.0
91.0	91.	35.2	65.9	167.3	552.0	.0
92.0	92.	37.2	70.2	180.8	604.5	.0
93.0	93.	39.3	74.9	195.3	662.1	.0
94.0	94.	41.4	79.8	210.9	725.0	.0
95.0	95.	43.7	85.1	227.8	790.4	.0
96.0	96.	42.5	90.7	246.0	869.5	.0
97.0	97.	44.9	96.7	265.6	952.1	.0
98.0	98.	47.3	103.0	286.8	1042.6	.0
99.0	99.	49.9	109.8	309.7	1141.6	.0
100.0	100.	52.6	117.0	334.3	1249.9	.0
101.0	101.	55.4	124.6	360.9	1368.5	.0
102.0	102.	58.4	132.8	389.0	.0	.0
103.0	103.	61.5	141.4	419.3	.0	.0
104.0	104.	64.9	150.6	451.9	.0	.0
105.0	105.	68.4	160.5	487.0	.0	.0
106.0	106.	72.0	170.9	524.8	.0	.0
107.0	107.	75.9	182.0	565.5	.0	.0
108.0	108.	80.0	193.8	609.3	.0	.0
109.0	109.	84.2	206.4	655.9	.0	.0
110.0	110.	88.8	219.8	706.1	.0	.0
111.0	111.	93.5	234.0	760.1	.0	.0
112.0	112.	98.5	249.1	818.2	.0	.0
113.0	113.	103.7	265.2	880.7	.0	.0
114.0	114.	109.3	282.3	948.0	.0	.0
115.0	115.	115.1	300.5	1020.4	.0	.0
116.0	116.	121.2	319.8	1098.4	.0	.0
117.0	117.	127.6	340.4	1182.2	.0	.0
118.0	118.	134.4	362.3	1272.4	.0	.0
119.0	119.	141.5	385.6	1369.5	.0	.0
120.0	120.	149.0	410.3	1473.9	.0	.0
121.0	121.	156.9	436.6	1586.3	.0	.0
122.0	122.	165.1	464.6	1707.2	.0	.0
123.0	123.	173.8	494.3	1837.3	.0	.0
124.0	124.	183.0	525.9	1977.3	.0	.0
125.0	125.	192.6	559.4	2127.9	.0	.0
126.0	126.	202.8	594.3	.0	.0	.0
127.0	127.	213.4	631.5	.0	.0	.0
128.0	128.	224.4	671.0	.0	.0	.0

Table VI-2 (Continued)

TERIAL DENSITY (gm/cm^3)	8	9	10	11	12
MATERIAL ICKNESS (MM)	SFD (CM)		EXPOSURE TIME (MIN)		
129.0	129.	236.4	712.9	.0	.0	.0
130.0	130.	248.8	757.4	.0	.0	.0
131.0	131.	261.8	804.7	.0	.0	.0
132.0	132.	275.5	854.9	.0	.0	.0
133.0	133.	289.9	908.2	.0	.0	.0
134.0	134.	305.0	964.2	.0	.0	.0
135.0	135.	321.0	1023.5	.0	.0	.0
136.0	136.	337.7	1086.5	.0	.0	.0
137.0	137.	355.3	1153.3	.0	.0	.0
138.0	138.	373.8	1224.1	.0	.0	.0
139.0	139.	393.2	1299.4	.0	.0	.0
140.0	140.	413.6	1379.2	.0	.0	.0
141.0	141.	435.1	1463.9	.0	.0	.0
142.0	142.	457.7	1553.8	.0	.0	.0
143.0	143.	481.4	1649.2	.0	.0	.0
144.0	144.	506.3	1750.4	.0	.0	.0
145.0	145.	532.5	1857.8	.0	.0	.0
146.0	146.	560.1	1971.8	.0	.0	.0
147.0	147.	589.0	2092.7	.0	.0	.0
148.0	148.	619.4	2221.0	.0	.0	.0
149.0	149.	651.4	2357.2	.0	.0	.0
150.0	150.	685.0	2501.7	.0	.0	.0

Table VI-3

Exposure Table for Cesium 137
According to Material Densities
from 1.0 gm/cm^3 to 5.0 gm/cm^3

RADIOACTIVE SOURCE : CESIUM 137
R. SOURCE ACTIVITY : 30.0 CURIE
FILM TYPE : STRUCTURIX D7
FILM DENSITY : 2

MATERIAL DENSITY (gm/cm^3)		1	2	3	4	5
MATERIAL THICKNESS (MM)	SED (CM)	EXPOSURE TIME (MIN)				
20.0	50.	.0	.0	.0	.0	.0
21.0	50.	.0	.0	.0	.0	.0
22.0	50.	.0	.0	.0	.0	.0
23.0	50.	.0	.0	.0	.0	.0
24.0	50.	.0	.0	.0	.0	.0
25.0	50.	.0	.0	.0	.0	.0
26.0	50.	.0	.0	.0	.0	.0
27.0	50.	.0	.0	.0	.0	.0
28.0	50.	.0	.0	.0	.0	.0
29.0	50.	.0	.0	.0	.0	.0
30.0	50.	.0	.0	.0	.0	2.2
31.0	50.	.0	.0	.0	.0	2.3
32.0	50.	.0	.0	.0	.0	2.3
33.0	50.	.0	.0	.0	.0	2.3
34.0	50.	.0	.0	.0	.0	2.3
35.0	50.	.0	.0	.0	2.2	2.4
36.0	50.	.0	.0	.0	2.2	2.4
37.0	50.	.0	.0	.0	2.3	2.4
38.0	50.	.0	.0	.0	2.3	2.5
39.0	50.	.0	.0	.0	2.3	2.5
40.0	50.	.0	.0	.0	2.3	2.6
41.0	50.	.0	.0	2.2	2.4	2.6
42.0	50.	.0	.0	2.2	2.4	2.6
43.0	50.	.0	.0	2.2	2.4	2.7
44.0	50.	.0	.0	2.3	2.4	2.7
45.0	50.	.0	.0	2.3	2.5	2.8
46.0	50.	.0	.0	2.3	2.5	2.8
47.0	50.	.0	.0	2.3	2.5	2.8
48.0	50.	.0	2.2	2.3	2.6	2.9
49.0	50.	.0	2.2	2.4	2.6	2.9
50.0	50.	.0	2.2	2.4	2.6	3.0
51.0	51.	.0	2.4	2.5	2.8	3.2
52.0	52.	.0	2.5	2.6	2.9	3.3
53.0	53.	.0	2.6	2.8	3.1	3.5
54.0	54.	2.6	2.7	2.9	3.2	3.7
55.0	55.	2.7	2.8	3.0	3.4	3.9
56.0	56.	2.8	3.0	3.2	3.5	4.2
57.0	57.	2.9	3.1	3.3	3.7	4.4
58.0	58.	3.1	3.2	3.5	3.9	4.6

Table VI-3 (Continued)

ATERIAL DENSITY (gm/cm^3)	1	2	3	4	5
MATERIAL THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)			
59.0	59.	3.2	3.4	3.7	4.1	4.9
60.0	60.	3.3	3.5	3.8	4.3	5.1
61.0	61.	3.4	3.7	4.0	4.5	5.4
62.0	62.	3.6	3.8	4.2	4.7	5.7
63.0	63.	3.7	4.0	4.4	4.9	6.0
64.0	64.	3.9	4.1	4.5	5.2	6.3
65.0	65.	4.0	4.3	4.7	5.4	6.6
66.0	66.	4.2	4.5	4.9	5.7	6.9
67.0	67.	4.3	4.7	5.1	5.9	7.3
68.0	68.	4.5	4.8	5.4	6.2	7.6
69.0	69.	4.7	5.0	5.6	6.5	8.0
70.0	70.	4.8	5.2	5.8	6.8	8.3
71.0	71.	5.0	5.4	6.1	7.1	8.7
72.0	72.	5.2	5.6	6.3	7.4	9.1
73.0	73.	5.4	5.9	6.6	7.7	9.5
74.0	74.	5.6	6.1	6.8	8.0	10.0
75.0	75.	5.8	6.3	7.1	8.4	10.4
76.0	76.	6.0	6.5	7.4	8.7	10.9
77.0	77.	6.2	6.8	7.7	9.1	11.4
78.0	78.	6.4	7.0	8.0	9.5	11.9
79.0	79.	6.6	7.3	8.3	9.9	12.4
80.0	80.	6.9	7.5	8.6	10.3	13.0
81.0	81.	7.1	7.8	8.9	10.7	13.5
82.0	82.	7.3	8.1	9.3	11.2	14.1
83.0	83.	7.6	8.4	9.6	11.6	14.8
84.0	84.	7.8	8.7	10.0	12.0	15.4
85.0	85.	8.1	9.0	10.3	12.5	16.1
86.0	86.	8.3	9.3	10.7	13.0	16.7
87.0	87.	8.6	9.6	11.1	13.5	17.5
88.0	88.	8.9	9.9	11.5	14.0	18.2
89.0	89.	9.2	10.3	11.9	14.5	19.0
90.0	90.	9.5	10.6	12.4	15.0	19.8
91.0	91.	9.8	11.0	12.8	15.6	20.6
92.0	92.	10.1	11.3	13.3	16.2	21.5
93.0	93.	10.4	11.7	13.7	16.8	22.4
94.0	94.	10.7	12.1	14.2	17.4	23.4
95.0	95.	11.0	12.5	14.7	18.0	24.3
96.0	96.	11.4	12.9	15.2	18.7	25.3
97.0	97.	11.7	13.3	15.7	19.4	26.4
98.0	98.	12.1	13.7	16.2	20.1	27.5
99.0	99.	12.4	14.2	16.8	20.8	28.6
100.0	100.	12.8	14.6	17.3	21.6	29.8

Table VI-4
Exposure Table for Cesium 137
According to Material Densities
from 6.0 gm/cm^3 to 10.0 gm/cm^3

RADIOACTIVE SOURCE : CESIUM 137
R. SOURCE ACTIVITY : 30.0 CURIE
FILM TYPE : STRUCTURIX D7
FILM DENSITY : 2

ATERIAL DENSITY (gm/cm^3)	6	7	8	9	10
MATERIAL HICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)			
20.0	50.	.0	2.3	2.6	3.2	4.6
21.0	50.	.0	2.3	2.6	3.3	4.9
22.0	50.	.0	2.3	2.7	3.5	5.2
23.0	50.	.0	2.4	2.8	3.7	5.6
24.0	50.	2.2	2.4	2.9	3.8	6.0
25.0	50.	2.2	2.5	3.0	4.0	6.4
26.0	50.	2.3	2.6	3.1	4.2	6.9
27.0	50.	2.3	2.6	3.2	4.4	7.4
28.0	50.	2.4	2.7	3.3	4.6	8.0
29.0	50.	2.4	2.7	3.4	4.8	8.7
30.0	50.	2.4	2.8	3.6	5.1	9.4
31.0	50.	2.5	2.9	3.7	5.3	10.1
32.0	50.	2.5	3.0	3.8	5.6	11.0
33.0	50.	2.6	3.0	4.0	5.9	11.9
34.0	50.	2.6	3.1	4.1	6.2	12.9
35.0	50.	2.7	3.2	4.3	6.5	14.0
36.0	50.	2.7	3.3	4.4	6.9	15.3
37.0	50.	2.8	3.4	4.6	7.3	16.5
38.0	50.	2.8	3.5	4.7	7.7	17.8
39.0	50.	2.9	3.6	4.9	8.1	19.3
40.0	50.	2.9	3.7	5.1	8.6	20.8
41.0	50.	3.0	3.8	5.2	9.1	22.6
42.0	50.	3.1	3.9	5.4	9.6	24.5
43.0	50.	3.1	4.0	5.7	10.2	26.6
44.0	50.	3.2	4.1	5.9	10.8	28.8
45.0	50.	3.3	4.2	6.1	11.4	31.3
46.0	50.	3.3	4.3	6.3	12.1	34.1
47.0	50.	3.4	4.4	6.6	12.8	37.1
48.0	50.	3.5	4.6	6.9	13.6	40.4
49.0	50.	3.6	4.7	7.1	14.4	44.0
50.0	50.	3.6	4.8	7.4	15.3	47.9
51.0	51.	3.9	5.2	8.1	16.9	54.4
52.0	52.	4.1	5.5	8.7	18.6	61.7
53.0	53.	4.4	5.9	9.4	20.4	.0
54.0	54.	4.7	6.3	10.2	22.4	.0
55.0	55.	4.9	6.7	11.1	24.6	.0
56.0	56.	5.2	7.2	12.0	27.0	.0
57.0	57.	5.5	7.6	12.9	29.6	.0
58.0	58.	5.8	8.1	14.0	32.5	.0

Table VI-4 (Continued)

ATERIAL DENSITY (gm/cm^3)	6	7	8	9	10
MATERIAL THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)			
59.0	59.	6.2	8.7	15.1	35.7	.0
60.0	60.	6.5	9.3	16.3	39.1	.0
61.0	61.	6.9	9.9	17.6	42.9	.0
62.0	62.	7.3	10.5	19.0	47.1	.0
63.0	63.	7.7	11.2	20.5	51.6	.0
64.0	64.	8.1	11.9	22.1	56.6	.0
65.0	65.	8.5	12.7	23.9	62.1	.0
66.0	66.	9.0	13.5	25.7	68.0	.0
67.0	67.	9.5	14.3	27.7	74.6	.0
68.0	68.	10.0	15.2	29.8	81.7	.0
69.0	69.	10.5	16.2	32.0	89.5	.0
70.0	70.	11.1	17.2	34.3	98.1	.0
71.0	71.	11.7	18.3	36.8	107.4	.0
72.0	72.	12.3	19.5	39.5	117.7	.0
73.0	73.	12.9	20.7	42.3	.0	.0
74.0	74.	13.6	21.9	45.4	.0	.0
75.0	75.	14.3	23.3	48.7	.0	.0
76.0	76.	15.0	24.7	52.2	.0	.0
77.0	77.	15.8	26.3	55.9	.0	.0
78.0	78.	16.6	27.9	60.0	.0	.0
79.0	79.	17.5	29.6	64.3	.0	.0
80.0	80.	18.4	31.4	68.9	.0	.0
81.0	81.	19.3	33.3	73.8	.0	.0
82.0	82.	20.3	35.3	79.1	.0	.0
83.0	83.	21.3	37.4	84.8	.0	.0
84.0	84.	22.4	39.6	90.8	.0	.0
85.0	85.	23.5	42.0	97.3	.0	.0
86.0	86.	24.7	44.5	104.3	.0	.0
87.0	87.	25.9	47.2	111.7	.0	.0
88.0	88.	27.2	49.9	119.6	.0	.0
89.0	89.	28.5	52.6	128.1	.0	.0
90.0	90.	29.9	55.6	137.2	.0	.0
91.0	91.	31.4	58.7	146.9	.0	.0
92.0	92.	33.0	61.9	157.3	.0	.0
93.0	93.	34.6	65.4	168.4	.0	.0
94.0	94.	36.3	69.0	180.3	.0	.0
95.0	95.	38.0	72.8	193.0	.0	.0
96.0	96.	39.9	76.9	206.6	.0	.0
97.0	97.	41.8	81.1	.0	.0	.0
98.0	98.	43.8	85.6	.0	.0	.0
99.0	99.	45.9	90.4	.0	.0	.0
100.0	100.	48.1	95.3	.0	.0	.0

Table VI-5
Exposure Table for Iridium 192
According to Material Densities
from 1.0 gm/cm^3 to 5.0 gm/cm^3

RADIOACTIVE SOURCE : IRIDIUM 192
R. SOURCE ACTIVITY : 30.0 CURIE
FILM TYPE : STRUCTURIX D7
FILM DENSITY : 2

ATERIAL DENSITY (gm/cm^3)	1	2	3	4	5
MATERIAL	SFD (CM)	EXPOSURE TIME (MIN)			
HICKNESS (MM)					
12.0	50.	.0	.0	.0	.0	.0
13.0	50.	.0	.0	.0	.0	.0
14.0	50.	.0	.0	.0	.0	.0
15.0	50.	.0	.0	.0	.0	.0
16.0	50.	.0	.0	.0	.0	.0
17.0	50.	.0	.0	.0	.0	.0
18.0	50.	.0	.0	.0	.0	.0
19.0	50.	.0	.0	.0	.0	.0
20.0	50.	.0	.0	.0	.0	2.0
21.0	50.	.0	.0	.0	.0	2.0
22.0	50.	.0	.0	.0	.0	2.0
23.0	50.	.0	.0	.0	.0	2.1
24.0	50.	.0	.0	.0	2.0	2.1
25.0	50.	.0	.0	.0	2.0	2.1
26.0	50.	.0	.0	.0	2.0	2.2
27.0	50.	.0	.0	.0	2.0	2.2
28.0	50.	.0	.0	2.0	2.1	2.2
29.0	50.	.0	.0	2.0	2.1	2.3
30.0	50.	.0	.0	2.0	2.1	2.3
31.0	50.	.0	.0	2.0	2.1	2.4
32.0	50.	.0	2.0	2.0	2.2	2.4
33.0	50.	.0	2.0	2.1	2.2	2.4
34.0	50.	.0	2.0	2.1	2.2	2.5
35.0	50.	.0	2.0	2.1	2.3	2.5
36.0	50.	.0	2.0	2.1	2.3	2.6
37.0	50.	2.0	2.0	2.2	2.3	2.7
38.0	50.	2.0	2.1	2.2	2.4	2.7
39.0	50.	2.0	2.1	2.2	2.4	2.8
40.0	50.	2.0	2.1	2.2	2.5	2.8
41.0	50.	2.0	2.1	2.3	2.5	2.9
42.0	50.	2.0	2.1	2.3	2.5	2.9
43.0	50.	2.1	2.2	2.3	2.6	3.0
44.0	50.	2.1	2.2	2.4	2.6	3.1
45.0	50.	2.1	2.2	2.4	2.7	3.2
46.0	50.	2.1	2.2	2.4	2.7	3.2
47.0	50.	2.1	2.3	2.4	2.8	3.3
48.0	50.	2.1	2.3	2.5	2.8	3.4
49.0	50.	2.2	2.3	2.5	2.9	3.5
50.0	50.	2.2	2.3	2.6	2.9	3.5
51.0	51.	2.3	2.4	2.7	3.1	3.8

Table VI-5 (Continued)

TERIAL DENSITY (gm/cm^3)	1	2	3	4	5
MATERIAL	SFD (CM)	EXPOSURE TIME (MIN)			
HICKNESS (MM)					
52.0	52.	2.4	2.6	2.8	3.3	4.0
53.0	53.	2.5	2.7	3.0	3.5	4.3
54.0	54.	2.6	2.8	3.2	3.7	4.5
55.0	55.	2.8	3.0	3.3	3.9	4.8
56.0	56.	2.9	3.1	3.5	4.1	5.1
57.0	57.	3.0	3.3	3.7	4.3	5.4
58.0	58.	3.2	3.4	3.9	4.6	5.7
59.0	59.	3.3	3.6	4.1	4.8	6.0
60.0	60.	3.5	3.8	4.3	5.1	6.4
61.0	61.	3.6	3.9	4.5	5.3	6.7
62.0	62.	3.8	4.1	4.7	5.6	7.1
63.0	63.	3.9	4.3	4.9	5.9	7.5
64.0	64.	4.1	4.5	5.2	6.2	7.9
65.0	65.	4.3	4.7	5.4	6.5	8.4
66.0	66.	4.4	4.9	5.7	6.9	8.8
67.0	67.	4.6	5.1	5.9	7.2	9.3
68.0	68.	4.8	5.4	6.2	7.5	9.8
69.0	69.	5.0	5.6	6.5	7.9	10.4
70.0	70.	5.2	5.8	6.8	8.3	10.9
71.0	71.	5.4	6.1	7.1	8.7	11.5
72.0	72.	5.6	6.3	7.5	9.1	12.1
73.0	73.	5.9	6.6	7.8	9.5	12.8
74.0	74.	6.1	6.9	8.1	10.0	13.5
75.0	75.	6.3	7.2	8.5	10.4	14.2
76.0	76.	6.6	7.5	8.9	10.9	15.0
77.0	77.	6.8	7.8	9.2	11.4	15.7
78.0	78.	7.1	8.1	9.6	11.9	16.6
79.0	79.	7.4	8.4	10.0	12.5	17.5
80.0	80.	7.6	8.8	10.4	13.1	18.4
81.0	81.	7.9	9.1	10.8	13.7	19.3
82.0	82.	8.2	9.5	11.3	14.3	20.3
83.0	83.	8.5	9.8	11.7	14.9	21.4
84.0	84.	8.8	10.2	12.2	15.6	22.5
85.0	85.	9.2	10.6	12.7	16.3	23.7
86.0	86.	9.5	11.0	13.2	17.0	24.9
87.0	87.	9.8	11.5	13.7	17.8	26.2
88.0	88.	10.2	11.9	14.2	18.6	27.5
89.0	89.	10.6	12.3	14.8	19.4	28.9
90.0	90.	10.9	12.7	15.4	20.2	30.4
91.0	91.	11.3	13.2	16.0	21.1	31.9
92.0	92.	11.7	13.6	16.6	22.1	33.5
93.0	93.	12.1	14.1	17.2	23.0	35.2
94.0	94.	12.5	14.5	17.9	24.0	37.0
95.0	95.	13.0	15.1	18.6	25.1	38.9
96.0	96.	13.4	15.6	19.3	26.2	40.8
97.0	97.	13.9	16.2	20.0	27.3	42.8
98.0	98.	14.3	16.7	20.8	28.5	45.0
99.0	99.	14.8	17.3	21.6	29.7	47.2
100.0	100.	15.3	17.9	22.4	31.0	49.6

Table VI-6

Exposure Table for Iridium 192

According to Material Densities

from 6.0 gm/cm^3 to 5.0 gm/cm^3

RADIOACTIVE SOURCE : IRIDIUM 192

R. SOURCE ACTIVITY : 30.0 CURIE

FILM TYPE : STRUCTURIX D7

FILM DENSITY : 2

ATERIAL DENSITY (gm/cm^3)	6	7	8	9	10
MATERIAL	SFD (CM)	EXPOSURE TIME (MIN)			
HICKNESS (MM)					
12.0	50.	.0	.0	2.1	2.5	3.3
13.0	50.	.0	2.0	2.2	2.6	3.6
14.0	50.	.0	2.0	2.3	2.8	4.0
15.0	50.	.0	2.1	2.3	2.9	4.3
16.0	50.	2.0	2.1	2.4	3.1	4.7
17.0	50.	2.0	2.2	2.5	3.3	5.2
18.0	50.	2.0	2.2	2.7	3.6	5.7
19.0	50.	2.1	2.3	2.8	3.8	6.3
20.0	50.	2.1	2.4	2.9	4.0	6.9
21.0	50.	2.2	2.4	3.0	4.3	7.7
22.0	50.	2.2	2.5	3.2	4.5	8.5
23.0	50.	2.2	2.6	3.3	4.8	9.5
24.0	50.	2.3	2.7	3.5	5.2	10.6
25.0	50.	2.4	2.8	3.7	5.5	11.8
26.0	50.	2.4	2.9	3.8	5.9	13.2
27.0	50.	2.5	3.0	4.0	6.4	14.7
28.0	50.	2.5	3.1	4.2	6.8	16.3
29.0	50.	2.6	3.2	4.4	7.3	18.1
30.0	50.	2.7	3.3	4.6	7.9	20.2
31.0	50.	2.7	3.4	4.8	8.5	22.5
32.0	50.	2.8	3.6	5.0	9.2	25.2
33.0	50.	2.9	3.7	5.3	9.9	28.2
34.0	50.	3.0	3.8	5.6	10.7	31.5
35.0	50.	3.0	4.0	5.8	11.6	35.4
36.0	50.	3.1	4.1	6.2	12.5	39.7
37.0	50.	3.2	4.2	6.5	13.6	44.7
38.0	50.	3.3	4.4	6.8	14.6	50.3
39.0	50.	3.4	4.5	7.2	15.7	56.7
40.0	50.	3.5	4.7	7.6	17.0	63.9
41.0	50.	3.6	4.9	8.0	18.3	72.1
42.0	50.	3.7	5.1	8.5	19.7	81.4
43.0	50.	3.8	5.2	9.0	21.3	92.0
44.0	50.	3.9	5.4	9.5	23.0	104.1
45.0	50.	4.0	5.7	10.0	24.9	117.9
46.0	50.	4.1	5.9	10.6	27.0	133.5
47.0	50.	4.2	6.1	11.3	29.2	151.0
48.0	50.	4.3	6.4	11.9	31.7	169.9
49.0	50.	4.5	6.6	12.6	34.3	191.4
50.0	50.	4.6	6.9	13.4	37.3	.0
51.0	51.	4.9	7.5	14.8	42.1	.0

Table VI-6 (Continued)

ATERIAL DENSITY (gm/cm^3)	6	7	8	9	10
MATERIAL THICKNESS (MM)	SFD (CM)	EXPOSURE TIME (MIN)			
52.0	52.	5.3	8.1	16.2	47.6	.0
53.0	53.	5.6	8.8	17.8	53.7	.0
54.0	54.	6.0	9.5	19.5	60.7	.0
55.0	55.	6.4	10.3	21.4	68.5	.0
56.0	56.	6.9	11.1	23.4	77.3	.0
57.0	57.	7.3	12.0	25.7	87.3	.0
58.0	58.	7.8	13.0	28.2	98.5	.0
59.0	59.	8.3	14.0	30.9	111.1	.0
60.0	60.	8.9	15.1	33.8	125.3	.0
61.0	61.	9.5	16.4	37.0	141.3	.0
62.0	62.	10.1	17.7	40.5	159.3	.0
63.0	63.	10.8	19.1	44.4	179.6	.0
64.0	64.	11.5	20.6	48.6	202.4	.0
65.0	65.	12.2	22.2	53.2	228.1	.0
66.0	66.	13.0	23.9	58.3	256.7	.0
67.0	67.	13.9	25.8	63.8	287.6	.0
68.0	68.	14.8	27.6	69.8	322.3	.0
69.0	69.	15.7	29.7	76.3	361.1	.0
70.0	70.	16.7	31.8	83.5	.0	.0
71.0	71.	17.8	34.1	91.4	.0	.0
72.0	72.	18.9	36.6	100.0	.0	.0
73.0	73.	20.1	39.3	109.3	.0	.0
74.0	74.	21.4	42.1	119.6	.0	.0
75.0	75.	22.7	45.2	130.7	.0	.0
76.0	76.	24.1	48.4	143.0	.0	.0
77.0	77.	25.6	51.9	156.3	.0	.0
78.0	78.	27.2	55.7	170.8	.0	.0
79.0	79.	28.9	59.7	186.7	.0	.0
80.0	80.	30.7	64.0	204.1	.0	.0
81.0	81.	32.6	68.6	223.0	.0	.0
82.0	82.	34.6	73.5	243.7	.0	.0
83.0	83.	36.7	78.8	266.3	.0	.0
84.0	84.	39.0	84.4	290.9	.0	.0
85.0	85.	41.4	90.5	317.8	.0	.0
86.0	86.	43.7	96.9	347.1	.0	.0
87.0	87.	46.2	103.8	379.1	.0	.0
88.0	88.	48.8	111.3	414.0	.0	.0
89.0	89.	51.6	119.2	452.1	.0	.0
90.0	90.	54.5	127.7	492.2	.0	.0
91.0	91.	57.6	136.7	535.3	.0	.0
92.0	92.	60.9	146.5	582.1	.0	.0
93.0	93.	64.4	156.9	633.1	.0	.0
94.0	94.	68.0	168.0	688.5	.0	.0
95.0	95.	71.8	179.9	.0	.0	.0
96.0	96.	75.9	192.6	.0	.0	.0
97.0	97.	80.2	206.2	.0	.0	.0
98.0	98.	84.7	220.8	.0	.0	.0
99.0	99.	89.5	236.4	.0	.0	.0
100.0	100.	94.5	253.0	.0	.0	.0

APPENDIX VII

Improved exposure charts with 'Alternative Method'

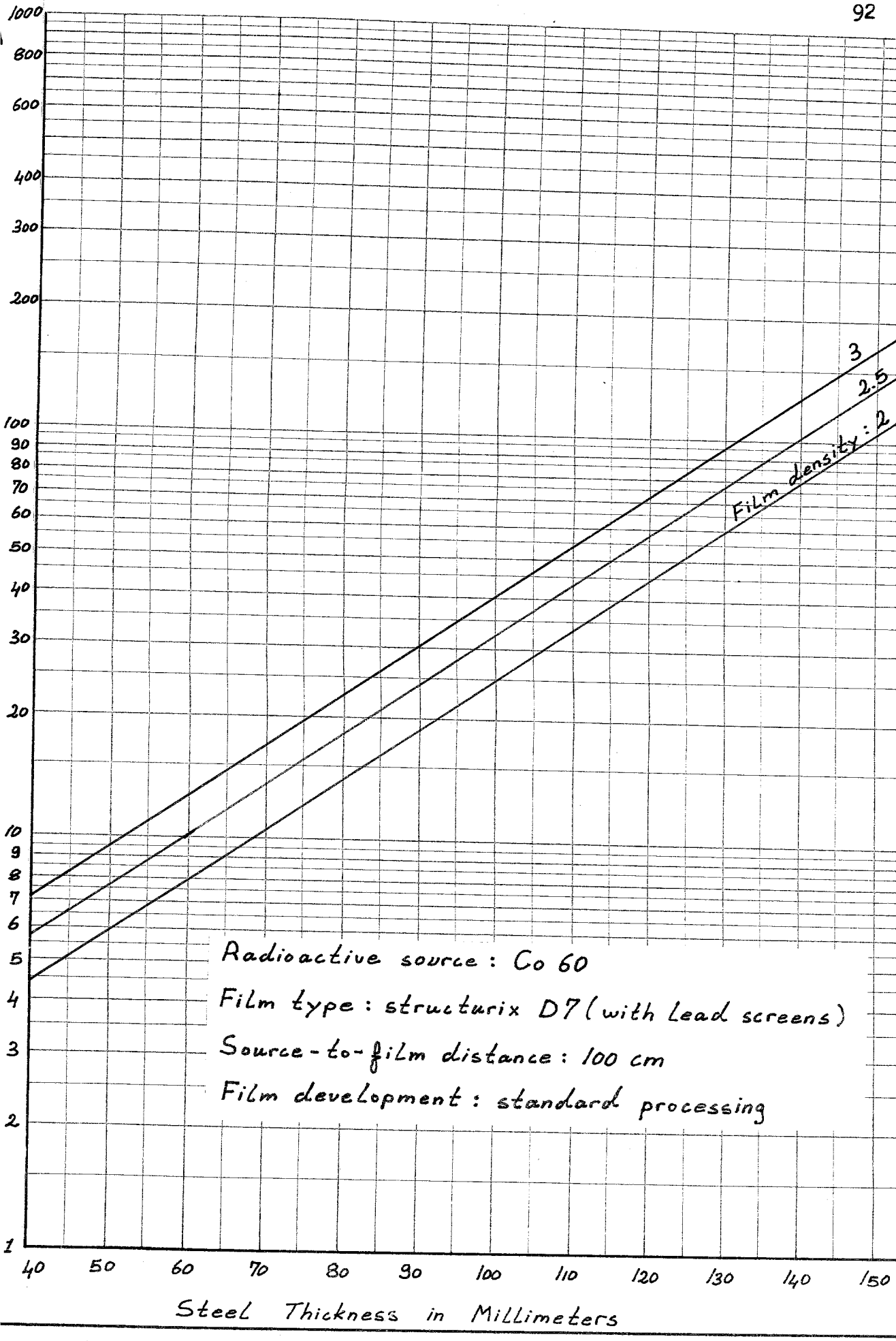


Table VII-1 Exposure chart according to material thicknesses

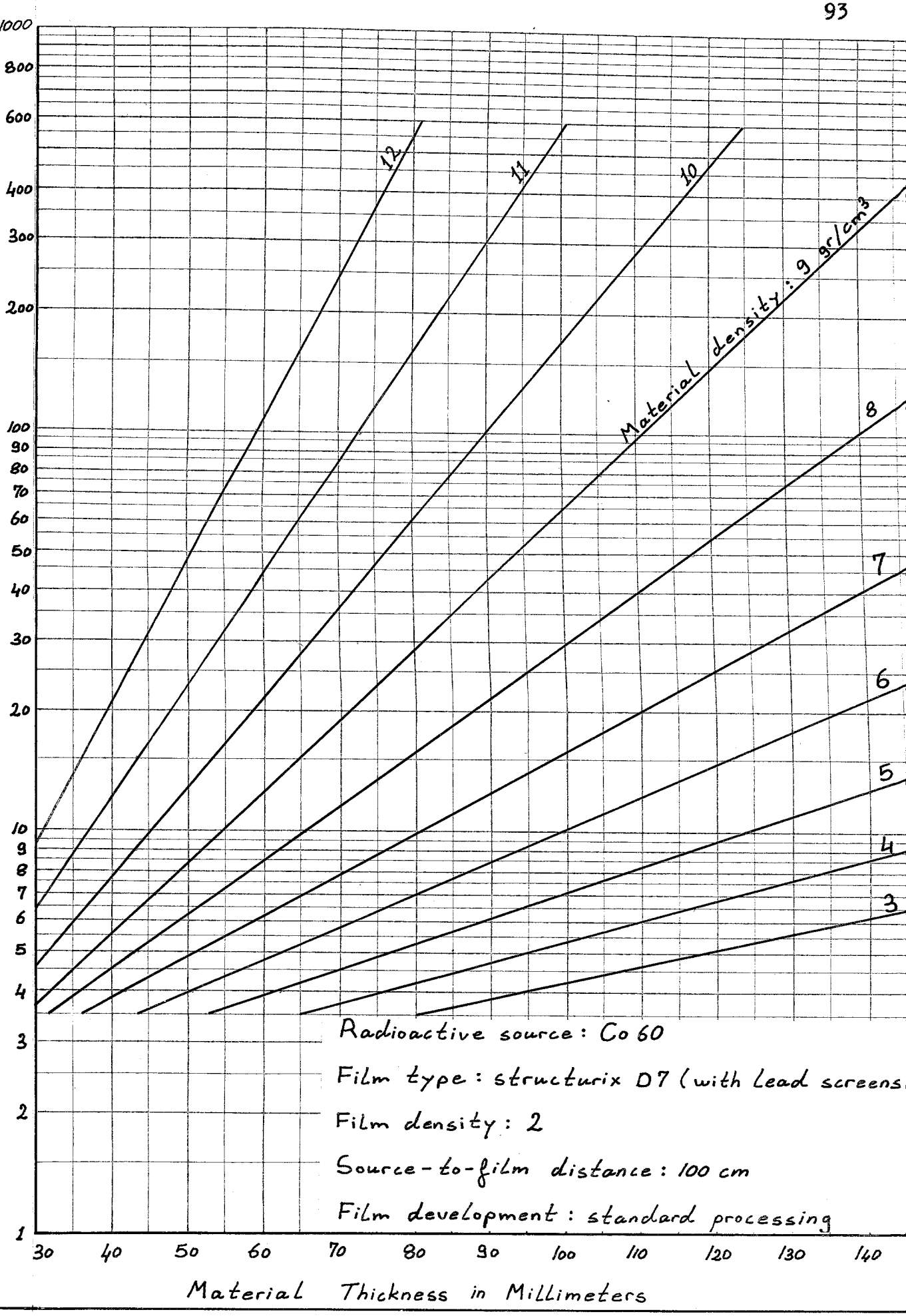


Table VII-2 Exposure chart according to material densities

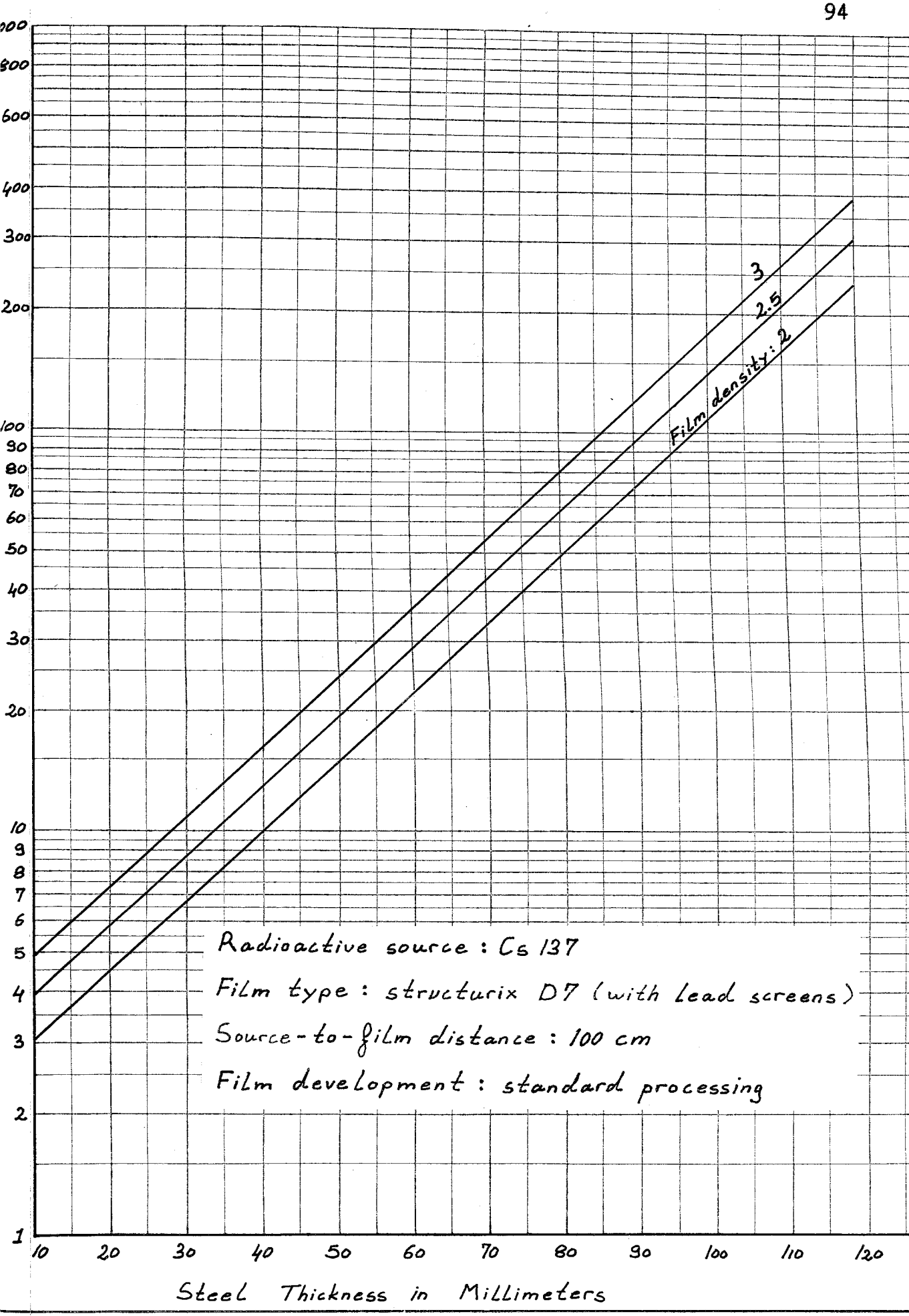


Table VII-3 Exposure chart according to material thichnesses

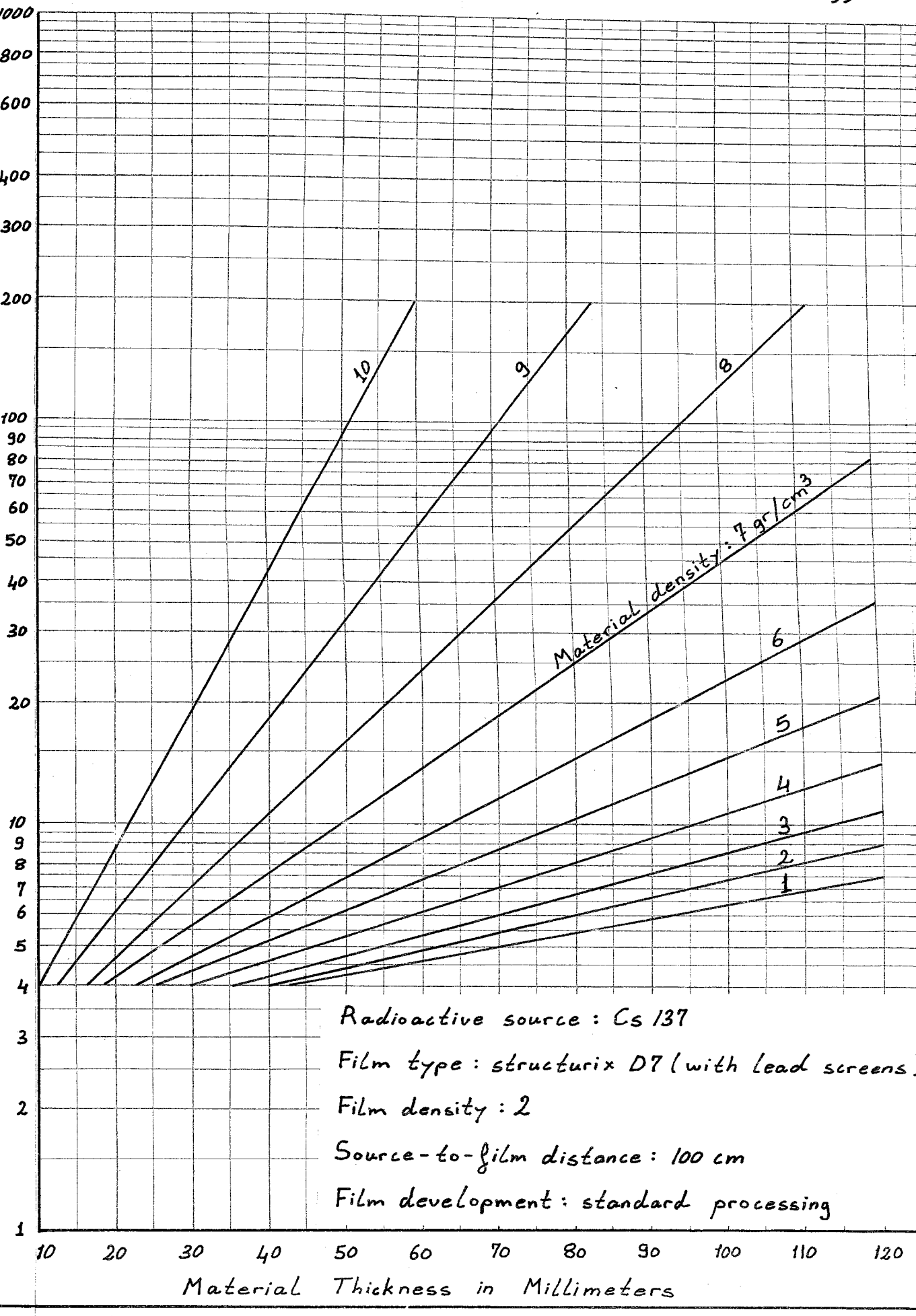


Table VII-4 Exposure chart according to material densities

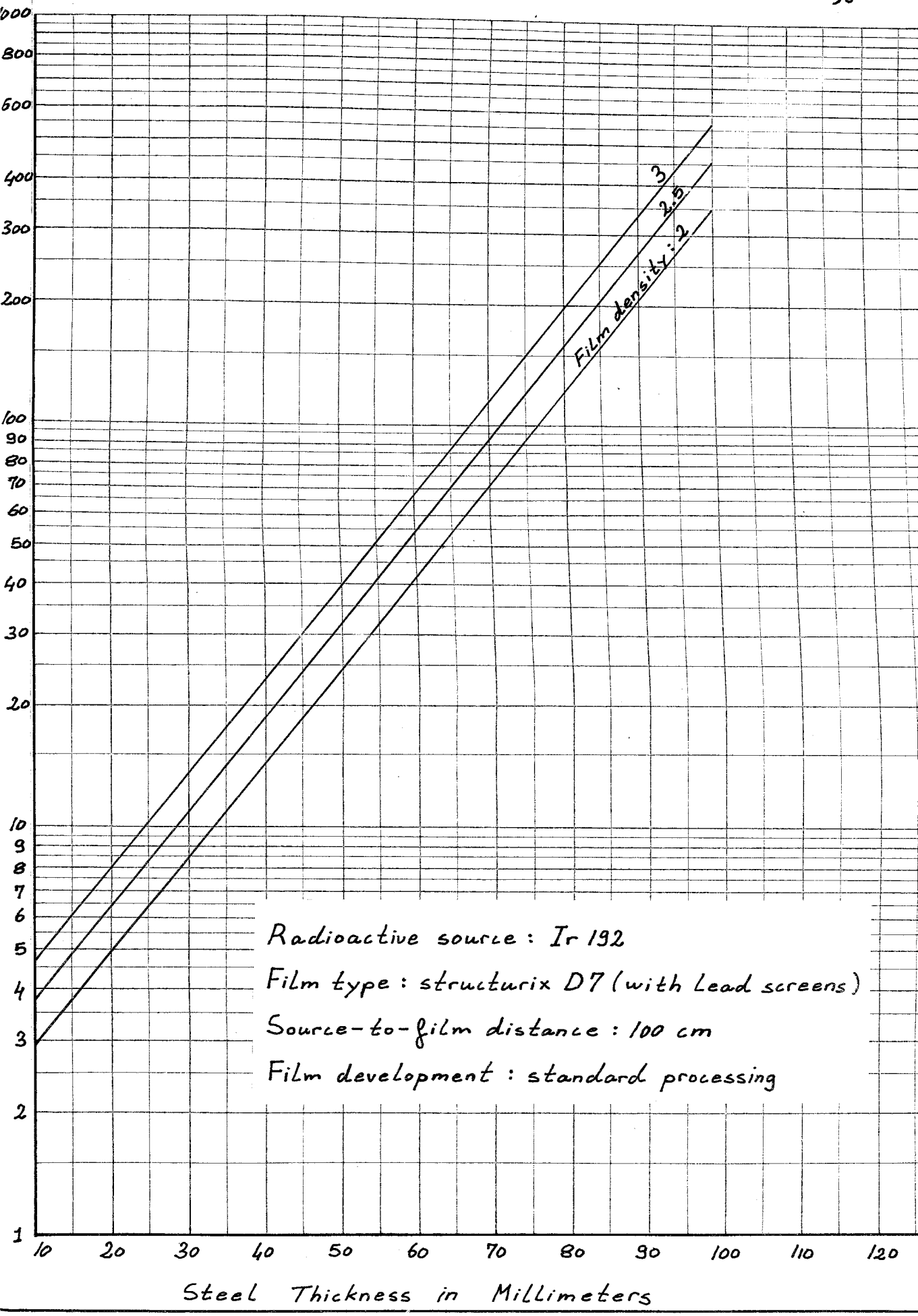


Table VII-5 Exposure chart according to material thicknesses

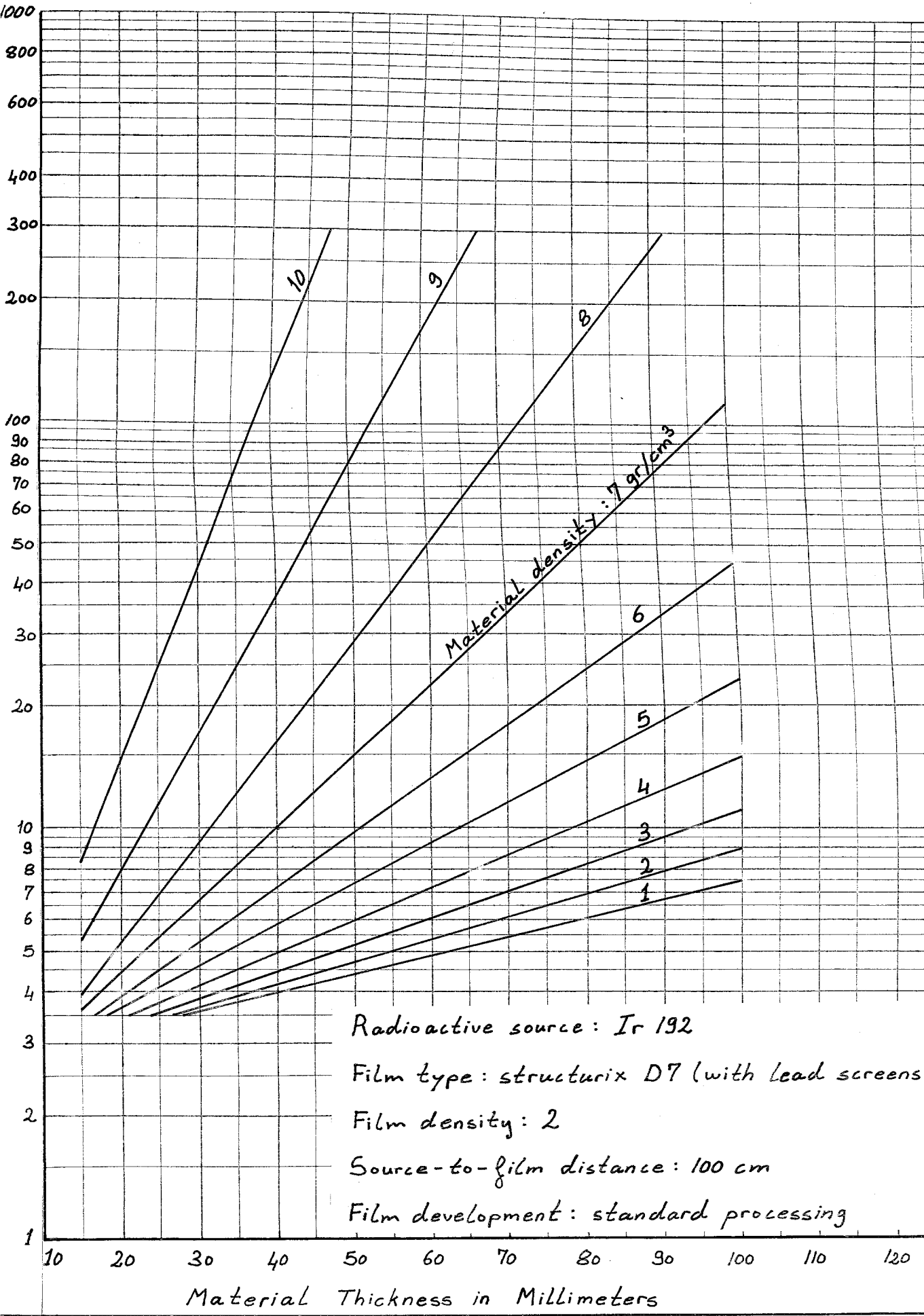


Table VII-6 Exposure chart according to material densities

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