CHARACTERIZATION OF GAMMAGRAPHIC RESOLUTION IN DIFFERENT MEDIA

by

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ABSTRACT

The determination of exposure time in radiography which is one of the most efficient methods of non-destructive testing has a great importance from the point of view of radiographic quality and reliability. In some applications, the test piece is situated in a medium other then air e.g. water or oil. The determination of exposure time in these situations is hardly done by conventional methods.

The relations between film density vs the height of medium and exposure time for 2.00 density vs the height of the medium were throughly inspected during the first part of the study by experimental work using Co-60 source. Later, the experimental results were compared with the theoretical ones and the formulas were modified according to the experimental results. This procedure was repeated for X-rays and similar results were obtained.

As a last step, the tables including time delay factors for different media were prepared. The main consideration in that part was the simplicity and the practicability of the tables. The practicians determining exposure time without taking the medium into consideration should just multiply the exposure time by the medium factor according to the height of the medium in order to get the required density on the film.

ÖZET

En önemli ve etkin tahribatsiz muayene metotlarından biri olan radyografide poz süresinin tayini radyografik kalite ve güvenilirlilik açısından büyük bir önem taşımaktadır. Ancak bazi uygulamalarda test parçası havadan başka su veya yağ gibi ikinci bir ortam içinde bulunabilmektedir. Böyle durumlarda poz süresi tayini bilinen metotlarla zorlukla yapılabılmektedir.

Bu çalişmanın ilk bölümünde film yoğunlugu ile ortam yüksekliği ve 2.00 film yoğunluğu için poz süresi ile ortam yüksekliği arasındaki ilişkiler Co-60 izotopu için deneysel olarak incelenmiştir. Daha sonra deneysel sonuçlar teorik neticelerle karşilaştırılmış ve buna göre formüller geliştirilmiştir.

Bu işlemler X-işınlarıyla da ayni şekilde tekrarlanmış ve bulunan bütün sonuçlar tablolar halinde verilmistir.

Son olarak farklı ortamlar ve farklı radyoizotoplar için ortam faktorleri tabloları hazırlanmıştır. Bu çalışmalarda göz önüne alınan en önemli nokta hazırlanan tabloların basit ve pratik olmasıdır. Ortami dikkate almadan poz süresini hesaplayan uygulamacılar sadece buldukları zaman ile ortam faktörunu çarparak gerekli poz süresini tespit edebilirler.

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a	Amount of reduced silver
A	Total amount of silver
B	Build up factor
d	Thickness
D_1, D_2	Distances
d1	Source to specimen distance
d2	Specimen to film distance
E(e)	Energy of the electron
E(γ)	Energy of the photon
E(b)	Binding energy
E(1)	Initial photon energy
F	Film factor
f(D)	Film factor
FDSFA	Film density factor
h_1, h_2	Exposure times
I(0)	Incident beam intensity
I(x)	Transmitted beam intensity
J, J_o	Light intensity
K_1, K_2, K_3	Constants
lsm	Least square method
Q_1, Q_2	Exposure
r1, r2	Distances
θ	Angle of scattering
S	Source strength
SFD	Source to film distance
t	Exposure time
t	Thickness
x	Thickness*density
x	Medium height
ψ	Effective absorption coefficient
ψ	Linear absorption coefficient
ψ	Mass attenuation coefficient
↑	Exponential

1. INTRODUCTION

The sudden rise of technologies which cannot tolerate any defect in materials they used promoted the methods inspecting products without destroying their serviceability. Nuclear technology is one of them. Every component used in a reactor or in a nuclear technique must be tested by several methods in order to ensure its reliability.

On the other hand, nuclear technology brings solutions to the problems of inspecting materials that conventional methods cannot. Nondestructive testing is one of these areas. Although there are several, effective nondestructive testing methods, radiography which is an application of nuclear techniques is an distinguished one among these tests by its reliability and effectiveness; moreover, radiography can be applied to many situations in which others cannot.

As nondestructive testing developes and becomes one of the pillars of modern technology, new applications are being employed. One of the basic considerations in these applications is that the test piece should be inspected in its original position; in other words, the specimen should not be brought to the test centre; instead, the radiographic test set must be brought to the piece under inspection.

This way of thinking saves time but it brings new problems. For example; if you are working under water, how will the radiographic equipment be protected against the effect of water and how will the exposure time be determined?

These kinds of problems are all being discussed in the world of industry. The main aim of this thesis is to find an efficient method for exposure time determination in different media. The radiation sources used in the

experimental work are restricted to only Co-60 radioisotope and X-rays but it will be a great help for us if the experimental work done here is supported by other studies on the other radioisotopes in different media.

2. NONDESTRUCTIVE TEST METHODS

2.1 Introduction

Nondestructive test methods (NDT) are widely used in industry to inspect the inside body defects of materials and products. Nondestructive tests are used to solve a great number of problems in such a way that does not adversely affect the serviceability of the products. Since the nondestructive characteristic of these tests gives 100 percent inspection, the uniform quality of products for critical uses can be assured.

The urgent needs of the progressing industries have required a great development in nondestructive testing; especially in the modern enginering fields since the middle of the 20th. century. For example, nuclear or aircraft technology cannot tolerate any defect in the product.

NDT methods also play an important role in quality control programs for different industrial products. They are not only used for products; but for raw materials and semi-manufactured materials. In other words, they can be used in every stage of the manufacturing processes to increase the quality of the products or even to establish a different technology developed for new products.

2.2 The Definition of Nondestrucive Inspection Test

"Nondestructive testing" is used for inspecting inner parts of a specimen without destroying it or its serviceability. The NDT methods are used not for detecting the design of the specimen; but its defects or weaker parts. In general, NDT methods are employed in the

applications where it is important to find the location and the importance of the defects.

One of the basic missions of NDT is to get detailed information about all of the defects present in the material. In other words; during the test, the flaws present in the material must be easily detected in detail. This plays an important role in rejecting or accepting the material under inspection.

2.3 General NDT Methods

The rapid progress in the methods for detecting flaws in materials has given rise to several, original techniques. Nowadays, it is possible to see that several, new and successful methods of nondestructive testing are widely employed in practical applications. The main advantages of NDT's over destructive testing are summarized below:

i) They are performed on the materials being used or manufactured. No other test piece or specimen is needed.

ii) They are employed on the manufacturing band.

iii) If desired, the tests can be made on a special part of the material.

iv) Most of the NDT tests are sensitive to different parts or characteristics of materials. According to the specialities of the utility desired, it is possible to use different methods and inspect different features of the material.

v) NDT's can easily be employed without delaying the manufacturing or repair processes.

vi) By using NDT's, it is possible to perform periodic control programs over the inspected part.

vii) Considerable cost savings in material and manufacturing can be made by using NDT's

viii) The preparation for NDT's is very easy and also takes a short time.

ix) Most of the NDT's are very fast and need very low labour cost. (7)

2.4 The Classication of the NDT's

The different needs of the several industries have promoted the development of the different nondustructive test methods. In this work, the focus will be given on the methods of flaw detection. The NDT techniques are presented here in five main categories;

1) Energy sources (X-rays, γ-rays, ultrasonic waves, ect.)
2) Signal or characteristics of vision
3) Determination of the last signal
4) Recording of signals
5) Interpretation of results

Today, the nondestructive test methods are classified into six different categories. These are;

1) Visual (Optical) methods
2) Ultrasonic methods
3) Eddy current
4) Magnetic particles
5) Dye-penetrants
6) Radiography

2.4.1 The Visual Methods or Optical Testing

The optical method uses the light scattered from the transparent solids in order to determine about the defects. In certain cases, the type of imperfection can be deduced from the studies of the distribution and polarization of the scattered light.

The visual examination can yield information about transparent and absorbing materials. If the specimen is a high absorbing material (e.g. metals) , these techniques can only be used for surface layer inspection (unless the specimen is employed in thin films). (8)

2.4.2 Ultrasonic Methods

The general process in this method is that the ultrasonic waves born out of a piezo-electrical material are directed into a test piece in order to give energy pulses. The waves advancing in the specimen are reflected back when they reach to a defect or to the borders of the material.

The ultrasonic waves, frequency of which are higher than 20 kHz can well be employed as an energy source and the pulse-echo technique is generally used for the signal character. The general determination method is by using a cathode ray tube; the amplitude of the echo from the defect is compared with the calibrated ones.

The main aim of ultrasonic testing is to find the borders of the test piece, the cracks or the defects in it. Ultrasonic flaw detecting is particularly succesful in the metallurgical industries where it is used for the inspection of semi-fabricated and many finished metal components.

2.4.3 Eddy Current Testing

The main principle of eddy current testing is to induce an alternating magnetic field on the surface of the test piece using an alternating current, to induce eddy currents inside the specimen and to detect the effect of flaws to eddy currents. The magnetic field is modified by one or more electrical properties of the test object such as electrical conductivity, magnetic permeability or electrical permeability. By using this method, the change of composition, the impurities on the surface or near the surface can easily be inspected. The main operational functions of the eddy current testing are summarized as follows;

1) Excitation of one or more test coils to produce an electromagnetic field within the test object,
2) Modulation of the electromagnetic field quantities by the test object,
3) Preparation of the test coil output signals,
4) Analysis of the test coil output signals,
5) Indication of the results of the analysis

An alternating current which has a frequency between 100 Hz and 6 MHz is used as the energy source. The signals are characterized by the changes in the magnetic field density. Flaws are detected by comparing the results with the standards. Fig 2.1 shows the schematic diagram of Eddy current testing.

The cracks, voids, inclusions, sediments and the dimensions or the locations of these can be inspected by magnetic methods. This test is specially suitable for metals. Very hot or cold objects can be tested by magnetic ways without contacting.

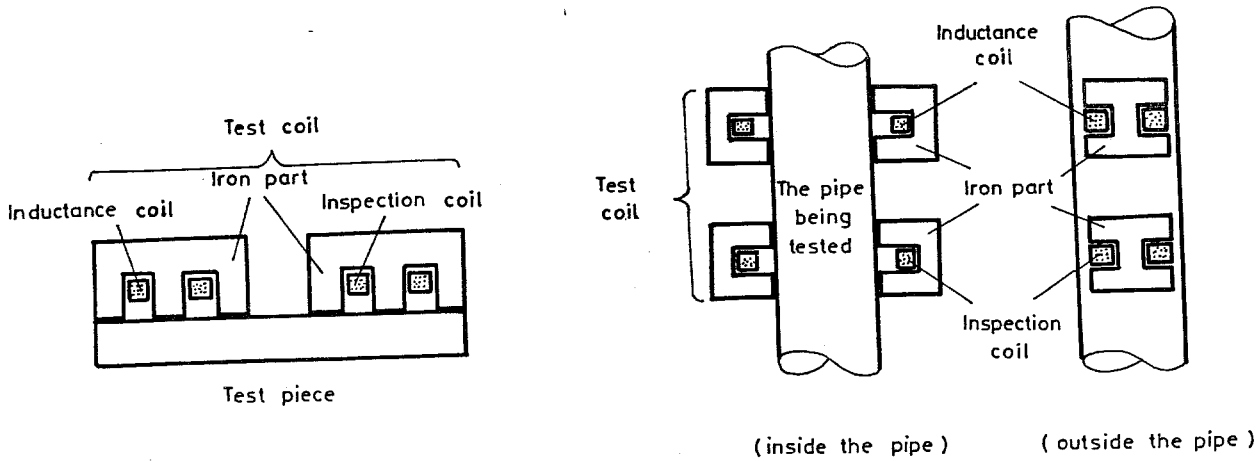


Fig 2.1 Schematic diagram of Eddy current testing

2.4.4 Magnetic Particles

The main process of magnetic particle testing is to apply magnetic dust which is contained in a penetrant liquid on the surface of a test piece. The dust will be lined along the cracks by the effect of the magnetic field.

The energy source used in this technique is the magnetic field induced on the test piece. The determination method is mainly by a rotating or oscillating coil. The results are recorded by a deflection meter; a graphic recorder. The definition of a defect needs comparing it with a standard one.

By using magnetic dust method, it is possible to find scratches, inclusions, cracks or holes. This method is suitable for metals. The defects near or on the surface can easily be inspected.

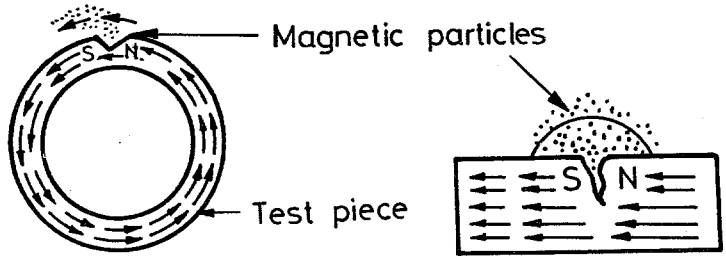


Fig 2.2 Magnetic testing

2.4.5 Dye-penetrant

The penetrant method utilizes the liquid dye leaking into the surface cracks of a test piece. After the inspecting of the surface, the flaws can be detected.

The only source used in this method is liquid dye. The dye is contaminated around the cracks by the capillary effect. The inspection can only be done by the eye. Although the defects are directly inspected, a standard one is seriously needed.

Dye-penetrant method is an effective one, especially in surface inspection. Metals and all solids which are not porous or highly absorbing can be effectively detected by this test.

A variation of this method employs radioactive gas instead of dye. This radioactive gas, which is generally Kr-85, leaks through the cracks on the surface and the dimensions and the locations of the flaws are revealed from the β-radiation of the gas.

The radioactivity of the gas is detected by a crystal detector and metalurgical pieces, components of machines and turbine blades or discs are usually checked by this method.

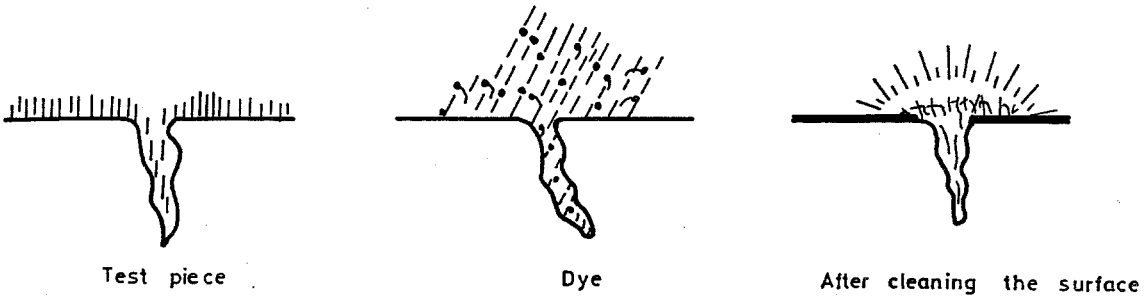


Fig 2.3 Schematic diagram of Dye-penetrant testing

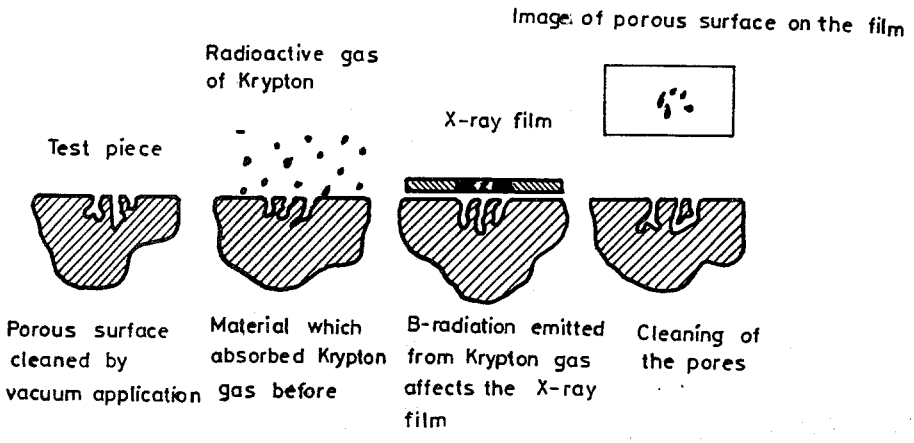


Fig 2.4 Radioactive gas test method

2.4.6 Radiography

Radiography provides a method of examining the inner structure of an opaque object for the presence of flaws, inclusions or shrinkages by passing a beam of penetrating radiation. Photographic films or fluoroscopic screens translate the amount of radiation into a two dimensional picture which shows the defects of the material. Since this thesis is devoted to radiography, the details will be discussed in the following chapters. (2)

3. ELECTROMAGNETIC RADIATION

3.1.1 X-rays and Principles

X-rays are electromagnetic radiation with wavelengths smaller than light. They are originated in two different ways. The first type of X-rays is produced when the stimulated K-shell electrons return back to their orbits after they are moved to a higher L or M shell and give off their excess energy in the form of X-ray photons in order to conserve energy. Since the energy levels of an atom; moreover, the differences between these levels are special characteristics of the atom, the X-ray produced is also a characteristic of the atom mentioned. The second type of X-rays is originated during the sudden stoppage of an accelerated electron by a target. When the electron collides with a target element, it will be decelerated by the electron atmosphere of the target atom. During this phenomenon, the electron will lose energy and the energy difference will be given as a X-ray photon, which is called "Bremsstrahlung" radiation.

The main properties of X-rays can be summarized as follows:

1) They have a strong power of penetration. They can be absorbed to a considerable amount during this phenomenon. The penetration depends upon the energy of the rays, density and thickness of the material.
2) They can be scattered; this will cause another scattering of an electron or a less energetic photon.
3) They travel at straight lines. Being electromagnetic radiation, they can be reflected, refracted and diffracted.

4) They cannot be felt by human senses.
5) They cause materials to fluoresce.
6) They affect photographic emulsions.
7) They obey the inverse square law to which intensity of X-rays at a point is inversely proportional to the square of the distance between the source and the point.
8) They cause ionization. They can detact electrons from the atoms of a gas, producing negative and positive electrons, so they are harmful to living cells.

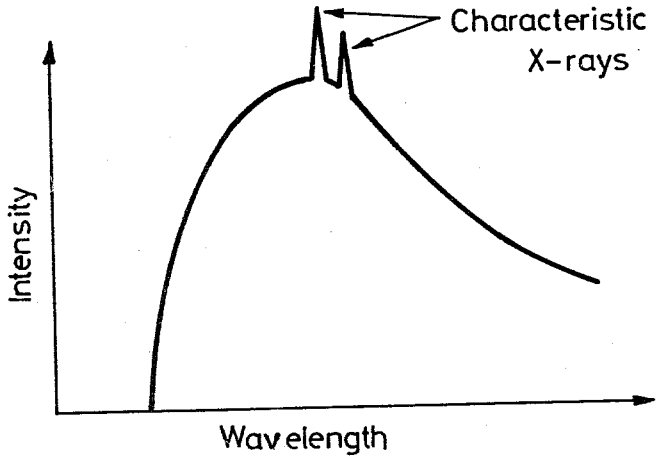


Fig 3.1 X-ray spectrum

3.1.2 Production in X-ray Tubes

X-rays are produced when the electrons traveling at high speed collide with matter. An X-ray tube has a heated filament as a source of electrons and a heavy metal target. The sudden stoppage of the accelerated electrons in the target results in the generation of X-rays. The area of the target on which the electrons strike is known as the focal point. Electrons, while passing close to the nucleus, interact with the nuclear field and get decelerated. The

loss of energy of the electrons is emitted as X-rays. The wavelength of the X-ray produced depends upon the energy loss of an electron. Striking electrons also interact with the inner shell electrons of the atoms of the target material. The atoms get ionized and emit characteristic X-rays. The X-ray spectrum is therefore continuous with definite minimum wavelength. The characteristic X-rays of the target material are superimposed on the spectrum which is shown in Fig 3.1.

3.1.3 X-Ray Equipment for Industrial Radiography

The basic components of X-ray equipment are the X-ray tube and the electrical devices necessary to energize and control the operation of the tube.

3.1.3.1 X-ray Tube

An X-ray tube consists of a glass envelope in which two electrodes are fitted: a cathode and an anode. The cathode serves as a source of electrons. The electrons are first accelerated by appling a high voltage across the two electrodes. Then they are stopped suddenly by a solid target fitted in the anode. The sudden stoppage of electrons results in the generation of X-rays. Such tubes work in the order of 10^{-6} mm of Hg inside the glass envelope. A typical X-ray tube is shown in fig 3.2.

Electrons are emitted by heating the filament which also acts as the cathode. An independent circuit called the filament circuit is necessary to control the emission of electrons from the filament. In order to give the necessary high speed to the liberated electrons, a high voltage is applied between the electrodes. The collimator arranges the streams of electrons to focus into the anode. The collimated stream of electrons then strikes the target

fitted in the anode. The target material must have the following properties:

i) High atomic number
ii) High melting point
iii) High thermal conductivity

High atomic number gives the best efficiency of conversion of electron energy into X-rays. High melting point allows high tube currents for a given size of focal spot thereby providing large X-ray output. High thermal conductivity reduces the amount of evaporation of the target material, therefore increases the life of the tube. Usually the target material is made from tungsten, because of these properties. (3)

Most of the energy of the impinging electrons is dissipated as heat, so taking away of heat produced due to electron impacts is one of the major considerations in the design of X-ray tubes. The cooling is performed by liquid or gas coolant. The efficiency of the tube is very low at low voltage and increases as the voltage increases.

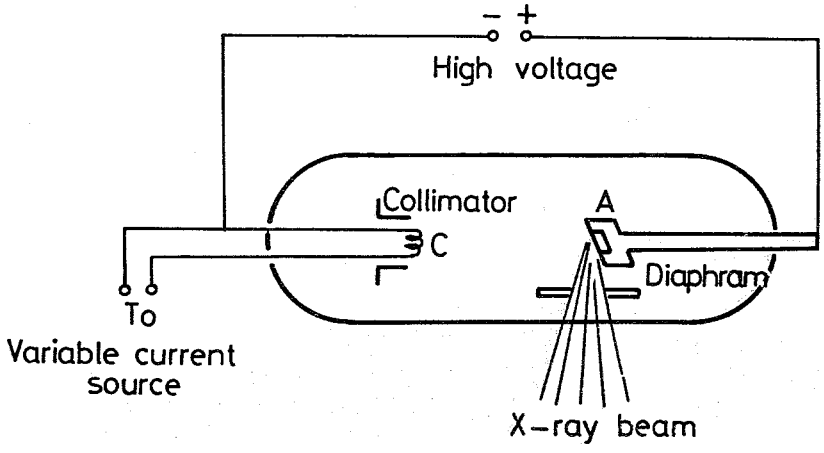


Fig 3.2 A typical X-ray tube

3.1.3.2 Electrical Devices Necessary to Energize and Control the Operation of the Tube and the Circuits

In addition to the X-ray tube, the necessary electrical equipment consists of:

i) A high voltage transformer to give the required voltage
ii) Gear to control the high voltage applied between the cathode and the anode
iii) Gear to control the filament current i.e. mA control knob
iv) Automatic trip system to protect the equipment from damage due to various causes.

3.1.4 Modern X-ray Equipment

The most important properties of versatile X-ray equipment are listed as follows;

1) Increased X-ray output with smaller size of the focal spot
2) Availability of very low and very high energetic X-rays
3) Portability or mobility of the units
4) Directional and panoramic X-ray outputs
5) Safe and simple operation of the equipment

3.2 Gamma Rays and their Interaction with Matter

3.2.1 Gamma Rays

Gamma rays are electromagnetic radiation like X-rays, but they have shorter wavelength and therefore they are more penetrating than the X-rays produced by the commonly

used industrial X-ray units. Gamma rays originate from the atomic nuclei unlike X-rays which are generated outside of the nucleus.

The actual values of wave lengths depend on the emitting radioactive source. All gamma sources have a line spectrum (discrete energies) unlike continuous spectrum of X-rays, shown in fig 3.3.

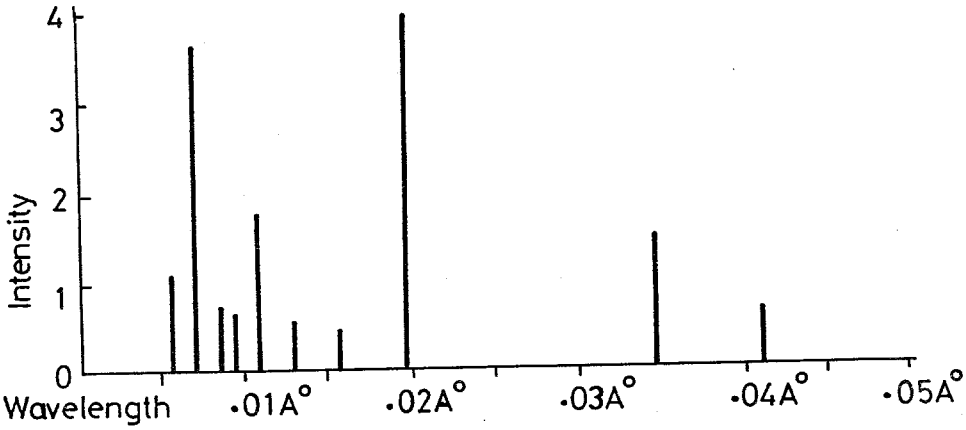


Fig 3.3 A typical line spectrum of gamma rays

3.2.2 Interaction of Electromagnetic Radiation with Matter

When a beam of electromagnetic radiation falls on an object, some part of it will be transmitted through, some part will be absorbed and some part will be scattered in all directions.

3.2.2.1 Absorption Phenomenon

A beam of E.M. radiation, while passing through a material, suffers loss in intensity. This phenomenon is called absorption of E.M. radiation in matter.
The amount of radiation loss depends on the quality of radiation, type of the material, density of the specimen and the thickness traversed. The intensity of E.M. is expressed as e.q. 3.1

$$I(x)=I(0)*\exp(-\mu*x) \qquad (3.1)$$

where;

I(0): incident beam intensity
I(x): transmitted beam intensity
x : thickness*density
μ : linear absorption coefficient which depends upon the incident radiation energy and the specimen material density or thickness

It is important to know what happens to the radiation which is considered lost in the absorption phenomenon. There are mainly 12 different modes in which electromagnetic radiation may interact with matter. In spite of this, only three of them, which are the dominant ones will be discussed in the text. The probability of a particular mode of interaction depends on the energy of incident photon and the specimen material.

3.2.2.2 Photoelectric Absorption

In this process photon gives up all its energy in ejecting an inner shell electron from the atom. The energy of the photon is used in knocking the electron out of the shell and giving it some kinetic energy. The ejected electron carries energy as:

$$E(e)=E(\gamma)-E(b) \qquad (3.2)$$

where;

E(e): Energy of the electron
E(γ): Energy of the photon
E(b): Binding energy

Photoelectric absorption process is most efficient when the interaction takes place with the most tightly bound electron of an atom. It is not possible for it to take place with the free electrons since a third body is needed to conserve momentum and energy.

Photoelectric absorption is most likely for a photon of low enery (E) and elements of high atomic number (Z) since electrons are more tightly bound to these atoms. The probability of photoelectric effect roughly varies as $1/E^{x}$ and $1/Z^{2}$.

3.2.2.3 Compton Scattering

A photon, similar to a particle, can transfer some of its energy to an electron, causing it to be deflected out of its orbital at a velocity, while the photon itself is scattered away at an angle with reduced energy. Momentum and energy are conserved during the collision. The relation between incident and previous photon energies is expressed as:

$$E(1)=0.51/(1-\cos\theta+(0.51/E(0))) \qquad (3.3)$$

E(1): Incident photon energy
E(0): Initial photon energy
θ : The angle of scattering

Compton scattering takes place with free electrons and with loosely bound outer shell electrons of the atom because these electrons behave virtually free to high energy photons. The probability of compton interaction varies linearly with the atomic number of the scattering material and decreases slowly with increasing photon energy. Compton scattering is more significant than photo electric absorption at intermediate photon energies.

3.2.2.4 Pair Production

If a γ photon of energy higher than 1.02 Mev passes by an atomic nucleus, the photon is annihilated in strong electrical field of the nucleus by creating a positive and a negative charged electron. Since the energy, equivalent to the sum of the masses of electron and positron, is 1.02 Mev, the energy of the incoming photon must be greater than this amount.

Pair production dominates other modes of interaction for photons of higher energies. The probability of this process increases rapidly with photon energies above 1.02 Mev and also increases as Z^2 of the stopping medium.

Since the positron cannot exist freely, electrons and positrons neutralize each other by radiating two photons of annihilation (0.51 Mev each).

3.3 Gamma Ray Sources for Industrial Application

The sources of radiation used in radiography are extremely small and is enclosed in sealed protective metal capsules. The activity of the gamma ray sources is expressed in curies or milicuries. The most commonly used radioisotopes are listed below with their special characteristics. (2,3,5,7)

3.3.1 Naturally Occuring Radioisotopes

There are several naturally occuring radioisotopes used in radiography, but here only the most important ones are discussed.

3.3.1.1 Radium-226

Radium source consists of about 200 to 250 mg of the element in the form of salt of the metal and is sealed in a

platinum capsule. Prominent energies emitted are 0.6, 1.12 and 1.76 Mev's which are comperable to the X-rays of operating voltage in 1000-2000 KV range.The half life of the isotope is 1590 years and the thickness range for which the source is used is 5 to 15 cm of steel.

3.3.1.2 Radon-222

Radon source consists of a quantity of radon gas absorbed in a small charcoal granule sealed in a glass capillary tubing which is contained in a sealed plantinum or gold capsule. Radon source has the same characteristics as that of radium expect that its half life is 3.825 days. The chief advantages of radon over radium is the smaller size of radon sources since large quantities of radon may be concentrated in a small charcoal granule.

The useful thickness range of Radon-222 is 5 to 25 cm of steel because of highly active small size sources.

3.3.2 Artificially Produced Radioisotopes

3.3.2.1 Cobalt-60

Cobalt-60 is a very commonly used radioisotope which is efficient for the radiography of 5 to 20 cm thick steel samples. Prominent energies are 1.17 and 1.33 Mev's. Half life is 5.3 years and one curie of Co-60 will give a dose of 1.35 rontgens per hour at one meter. It is available in 1x1 to 4x4 mm sizes, encapsulated in holders of aluminum alloy.

3.3.2.2 Cesium-137

It is a monochromatic source of 0.667 Mev gamma ray and is radiographically comparable to the X-rays of operating

voltage at 700 KV. The half life is 33 years and one curie of Cs-137 would produce a dose of 0.35 rontgens per hour at one meter. Steel thickness of 2 to 10 cm can be radiographed. The sources of 1 mCi to 1 Ci are available in pellet size of 3 mm dia. and lenght not more than 3 mm depending on their activity.

3.3.2.3 Thulium-170

Thulium sources give 0.084 Mev gamma ray which are comparable with X-rays of operating voltage at 120 KV. The half life is 127 days and 0.2 to 1.2 cm thick aluminum samples and up to 0.5 cm thick steel samples may be radiographed. The sources are available in 2x3 mm and 3x3 size pellets which are encapsuled in holders of aluminum alloy.

3.3.2.4 Iridium-192

Iridium-192 isotope has a half life of 74 days with a spectrum of energies with predomient lines of 0.13, 0.29, 0.58, 0.60 and 0.61 Mev's. The thickness range of radiography is 0.5 to 6 of steel and 1.0 to 10 cm of aluminum. The sources are encapsulated in holders of aluminum alloy and are available in different sizes varying from 0.5x0.5 mm to 6x6 mm.

3.3.3 Selection of a Gamma Ray Source

Selection of best suitable radioisotopes for particular applications requires that the following parameters should be taken into consideration;

3.3.3.1 Half Life

The source should a have half life long enough to complete the radiograph. If, due to other considerations, a short lived source is selected, it should have high initial activity.

3.3.3.2 Energy of Gamma Rays

Energy of gamma rays from the source must be sufficient to penetrate the thickness of the specimen to be radiographed. It is usual practice to restrict the thickness to the specified ranges to minimize the loss of radiographic quality.

3.3.3.3 Size of the Source

The size of the source should be small enough to minimize penumbra which decreases the quality of the radiograph.

3.3.3.4 Availability

The source must be easily available and preferably at low cost.

Finally, it is useful to note that Cobalt-60, Thulium-170 and Iridium-192 can be reactivated whereas Cesium-137 cannot be. Physical characteristics of the common used radiotopes are shown in table 3.1.

Table 3.1 General characteristics of the most commonly used isotopes

Source	Prominent Emitted energies (Mev)	Half life	Recomended thickness range	Normal source size	Dose rate per curie at one meter(r/h)
Ra-226	0.6, 1.12 1.76	1590y	5-15 cm of steel	2x2	0.83
Rn-222	0.6, 1.12 1.76	3.825d	5-25 cm of steel	.5x.5	0.83
Co-60	1.17, 1.33	5.3y	5-20 cm of steel	1x1-4x4	1.35
Cs-137	0.667	33y	2-10 cm of steel	1x1-3x3	0.33
Th-170	0.084	127d	0.5 cm of steel 0.2-1.2 cm of Al	2x3-3x3	0.0045
Ir-192	0.29,0.58 0.60,0.61	74d	0.5-6 cm of steel 1-10 cm of Al	.5x.5-4x4	0.5

4. GENERAL PRINCIPLES OF RADIOGRAPHY

4.1.1 Introduction

Industrial radiography is one of the most efficient methods of nondestructive testing. The word "Radiography" means recording the inner picture of a specimen with the help of radiation (X-rays, ɣ-rays) on a photographic film or a flouroscopic screen in two dimensions. The radiation coming from a source is recorded after it has passed through the specimen and a transparent image of the specimen is achieved.

4.1.2 Radiography with Electromagnetic Radiation

X-rays emitted in a continuous spectrum and gamma rays emitted in a line spectrum are mainly used in radiographic applications. Radioisotope sources that emit gamma rays have both advantages and disadvantages over X-ray tubes. These are:

As advantages:

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

As disadvantages:

1) They cannot be turned off.
2) The energy of the isotope cannot be varied after

the first selection.

3) There are few inexpensive low-energy sources available with long half lives.

The development of electron accelerators both linear and orbital in recent years created a very considerable interest in the use of X-rays for nondestructive testing. Compared with conventional X-ray machines up to 400 KV, the development of high energy generators of with a capacity above Mev's makes it possible to penetrate very thick steel or brass specimen in exposure times sufficiently short to be economic.

4.1.3 The Principle of Flaw Detection

During radiographic inspection, the image of the inner parts of the specimen on the photographic film is achieved by the absorption of electromagnetic radiation passing through the specimen.

If I(0), being the intensity of the radiation, passes through a material of thickness t with a flaw of thickness d, the change in intensity can be expressed as follows:

$$I(d)=I(0)*\exp(-\psi.(t-u)) \qquad (4.1)$$

But this expression is valid only if the flaw is a void. If the flaw is an inclusion, then the intensity of the radiation will be:

$$I(d)=I(0)*\exp(-\psi(t-u)*\exp(-\psi'.d) \qquad (4.2)$$

Where, ψ and ψ' signify the absorption coefficients of the material and the inclusion. The intensity of the radiation passing through the material is closely related

with the absorption coefficient of the material (μ). This also depends on the atomic number and the density of the material. (2)

4.2.1 Geometric Aspects of Radiographic Formation

A radiograph is an inside picture of an object recorded on a photographic film using a radiation source. The appearance of the picture of a defect is influenced by the following factors:

1) Shape of the defect,
2) Orientation of the defect with respect to the direction of radiation and the plane of the film,
3) Size of the source or focal spot of X-ray tube and its distances from the defect and the film.

Defects of different types will give rise to different pictures or images. The beam direction must be perpendicular to the specimen and the film, otherwise the image will be distorted. Because of this distortion, sometimes a particular defect may be interpreted as some other type of defect.

4.2.2 Size of the Source and its Distance from the Film

The ideal size of a source would be a point one. Since every point of the source emits radiation, the image cast by the defect onto the film will be the result of overlaping images cast by these points. The net effect is that the image is diffused around the boundaries. Schematic diagram of the radiographic principle is shown in fig 4.1.

The image may be divided into two portions:

1) Umbra: Where no direct rays are incident on the film.
2) Penumbra: The area which is partly exposed gives rise to a fuzziness in the image and is undesirable in radiography.

In order to increase the sharpness of the image:

i) Size of the source (or focal spot) should be as small as possible
ii) Source to film distance (SFD) should be as large as practical. A helpful formula will be :

$$d1 > 8 * d2 \qquad (4.3)$$

where;

d1: Film to specimen distance
d2: Thickness of the specimen

3) The film should be as close to the specimen as possible.

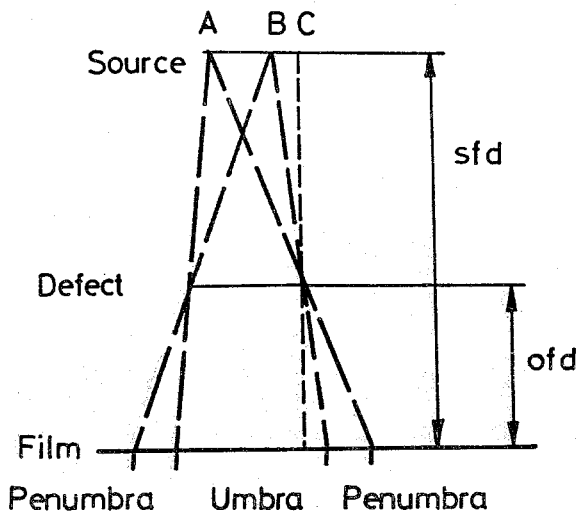


Fig 4.1 Geometric Unsharpness

4.3 Radiographic Quality Factors

The quality of a radiograph mainly depends upon three factors.

1) Density
2) Contrast
3) Definition

4.3.1 Density

Density is a measure of the degree of blackenning of the film. It can be mathematically stated as;

$$\text{Density} = \text{Log}_{10}(I_o/I_t) \qquad (4.4)$$

where, I_o is the intensity of light incident on the film and I_t is the intensity transmitted through it.

4.3.2 Contrast

It is defined as the difference between the densities of two adjacent areas in a radiograph.

4.3.3 Definition

Definition is a measure of the ability of a radiograph to resolve fine details. It is a measure of the sharpness of the image.

Objective measurements of density, contrast and the definition of a radiograph can be made with Quality Image Indicators. The interent contrast of a film depends upon density. For direct type X-ray films, it increases with density throughout the readable range. Optimum density

ranges for maximum radiographic sensivity by British Standard 2680. (3)

for 1) Direct type X-ray films with or without lead screens optimum density range is 1.7-3.0
2) Gamma ray exposures, density range is between 2.0- 3.0

4.3.4 Radiographic Exposure

The radiographic exposure is defined as the product of source strength and the time for which the film is exposed to radiation. In case of X-rays:

Exposure= Tube current (mA)x time(sec) (mA.s) (4.5)

and for gamma rays:

Exposure= Strength(Ci)x time(hour) (Curie-hour) (4.6)

4.3.5 Image Quality in Radiography

The method to measure radiographic sensivity is to increase artificially the thickness of the specimen by a device known as Image Quality Indicators, consisting of steps or wires of the same material as that of the specimen. (3) The radiographic sensivity which is also known as the sensivity of IQI is defined as the minimum detectable variation of thickness expressed as percentage of the specimen thickness. The IQI is placed on the source side of the specimen being radiographed. The dimensions of the thinnest step or wire visible in the radiograph is then used to calculate the radiographic sensitivity S(IQI) with the help of the following formula:

$$S(IQI)=(TSHW)/(\text{Specimen Thickness})*100 \qquad (4.7)$$

where;

TSHW= The thickness of the thinnest step with holes or wires visible in the radiograph.

The higher the value obtained, the poorer will be the radiographic sensivity.

4.3.6 Image Quality Indicators

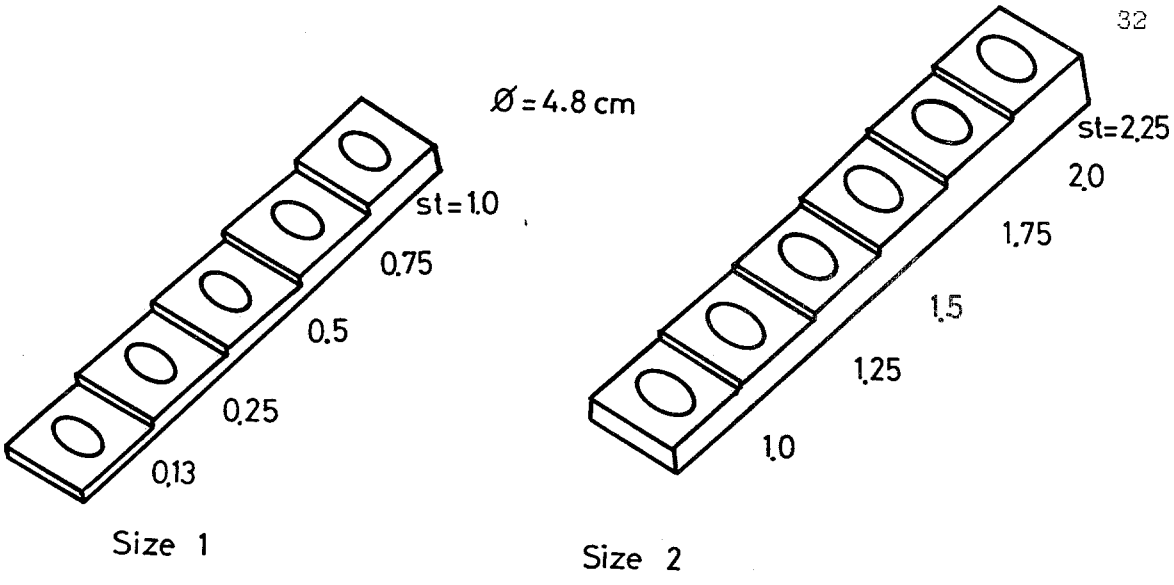
Image quality indicators are used to reveal radiographic sensivity. There are several types of them. The most important ones are listed below:

1) Flat type
2) Step with hole type
3) Wire type

Each IQI is identified by a lead number (I.D. No) which gives the maximum thickness of material for which the indicator is normally used. (1,4)

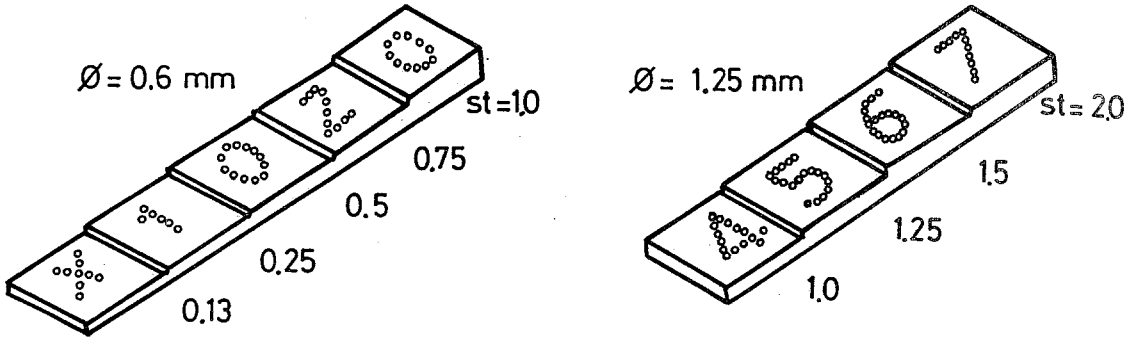
4.3.7 Factors Affecting Radiographic Quality

Several factors, the most important of which are listed below, affect the radiographic quality:



Size 1 Size 2

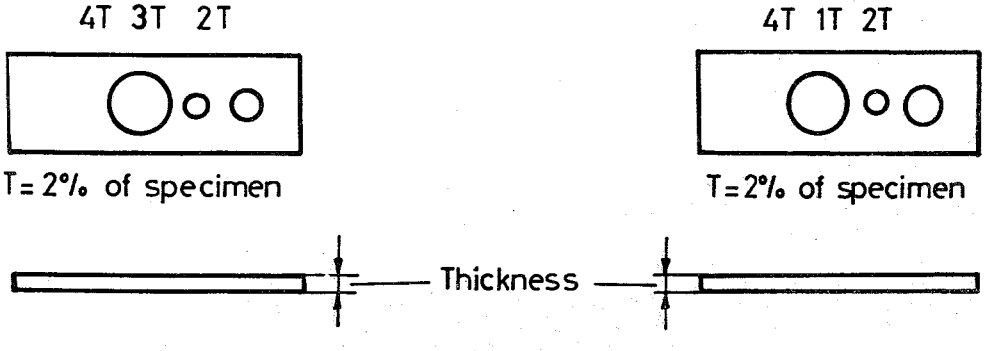
A. S. M. E. Image quality indicators



Size 1 Size 2

B. W. R. A. Image quality indicators.

st: step thickness



Sketch of A. S. M. E. flat type image quality indicator

Fig 4.2 Image Quality Indicators

4.3.7.1 Kilovoltage/ Type of radioactive source

Penetration increases and exposure is reduced with the increase in kilovoltage or by use of a higher energy source.

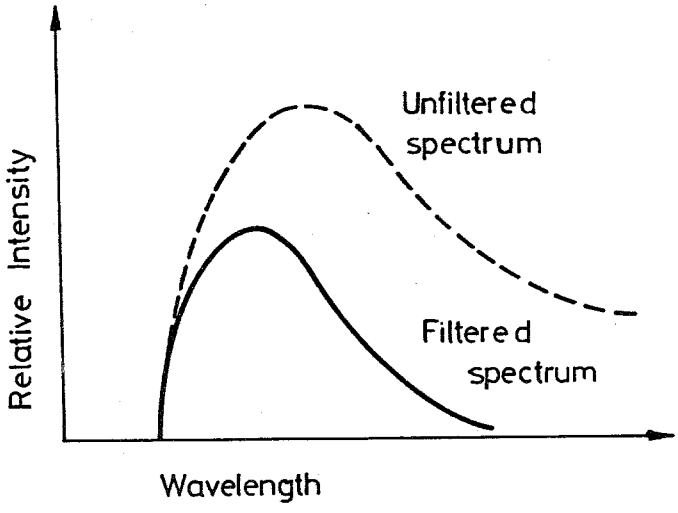


Fig 4.3 Effect of filtration on X-ray beam

4.3.7.2 Filtration

The use of filters reduces the intensity of the X-ray beam due to the absorption, thereby increasing the exposure and contrast as the lower energy component of the X-ray spectrum is absorbed by the filter as shown in fig 4.3.

4.3.7.3 Intensifying Screens

When a gamma or a X-ray beam comes in contact with the film, less than one percent of 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 the film, lead screens are used in pairs. These screens are put on each side of the film.

Depending upon the specimen and the energy of the radiation, the screens of varying thicknesses can be used. The front screen in many applications is thinner than the back screen. The thickness of the screens; 0.1 mm for the front and 0.15 mm for the back is advisable for gamma or X-ray sources. Lead screens also help in reducing the amount of scatter reaching the film, therefore improve the quality of the radiograph.

4.3.7.4 Specimen Thickness, Density and Atomic Number

The exposure increases and the contrast decreases with the increase in these quantities.

4.3.7.5 Development

The density, contrast and the graininess of radiograph are affected by the type, the temperature of the developer used, time of development and agitation.

4.3.7.6 Film Type

Exposure can be reduced by using a faster film but definition would also be reduced in this way.

4.3.7.7 Size of the Source

If the size of the source or the focal spot increases, penumbra (unsharpness) will increase hence the definition will be negatively affected.

4.3.7.8 Source to Film Distance (SFD)

Exposure is changed with the change of sfd according to the following formula:

$$E1/E2=r1^2/r2^2 \qquad (4.8)$$

where; E1 is exposure at sfd = r1
E2 is exposure at sfd = r2

4.3.7.9 Vibration of Source, Specimen and Film

If the specimen, the source of radiation and the film vibrate towards one another, overlapping images will be formed, thereby decreasing the definition.

4.3.7.10 Source Strength

An increase in miliamperage or strength of the source used will reduce the exposure. This variable has no effect on the quality of the radiograph.

4.4 Methods for Exposure Determination

Determination of correct radiographic time for a given specimen is very important to have the best results. Following methods may be advisable for exposure determination:

4.4.1 Reference to Previous Data

It is very important to keep a record of previous cases. This will be very helpful in determining the exposure for a specimen. If a similar specimen was exposed

in the past, the correct exposure time might be found under similar conditions.(1)

4.4.2 Use of Characteristic Curve

Characteristic curve of a film shows the relation between film density and the relative exposure for the film. This method can be used for samples made from mixed materials for which exposure chart is normally not available.(1)

Characteristic curve of a film is prepared by subjecting a strip of the film to varying amounts of exposure so that every strip will receive different amounts of exposure (X-rays or gamma rays). The strip is normally exposed in steps in order to assure that each step will receive twice the exposure of the previous step. After the development of the film, a density step-wedge is obtained. Then the densities of each step are plotted against the corresponding exposures and the required characteristic curve is obtained.(1,3)

Exposure time is found from the characteristic curve by trial and error. The trial exposure 'E_t' gives a density 'D_t' and the standard density required to be achieved is 'D_r'. The relative exposures corresponding to these densities can be read from the characteristic curve of the film. If we let 'E_{ct}' be the exposure corresponding to density 'D_t' and 'E_{cr}' corresponding to density 'D(r)' as read from the characteristic curve. Then the correct exposure time E to obtain the required density, is given by:

$$E/E_t=E_{cr}/E_{ct} \qquad (4.9)$$

The characteristic curve for a typical direct film is presented in fig 4.4.

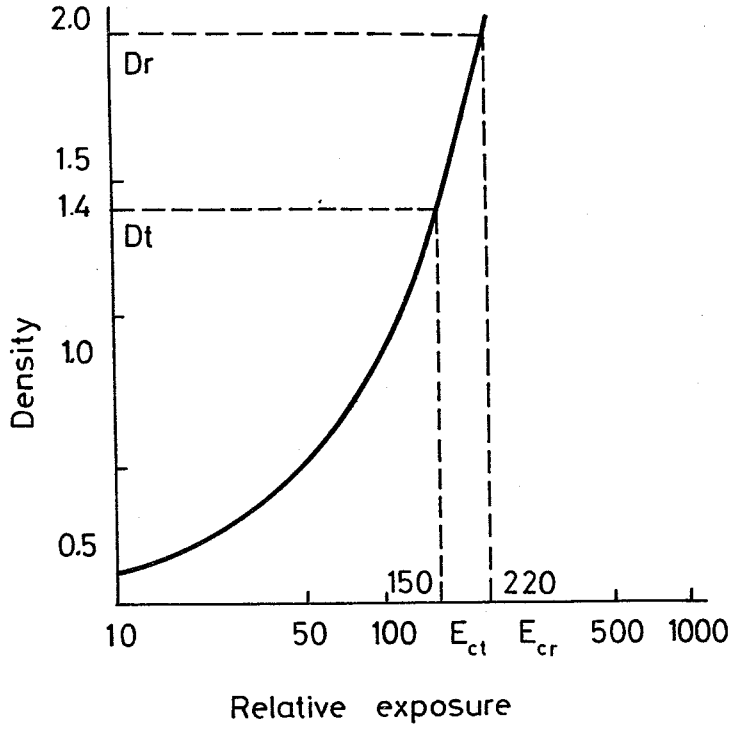
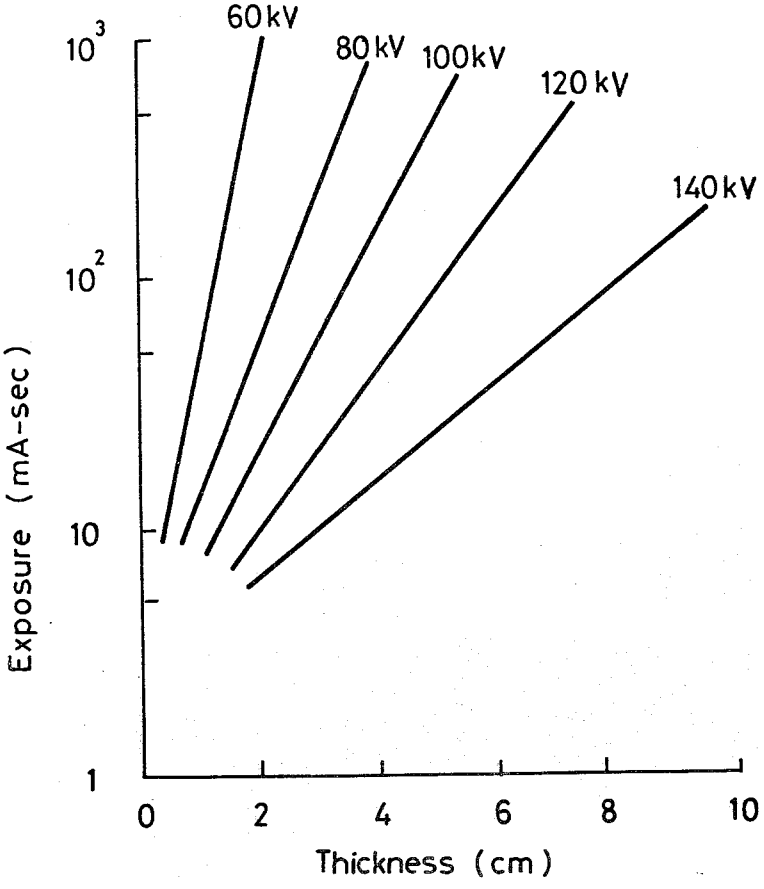


Fig 4.4 Characteristic curve for a direct film



MATERIAL	:	Aluminium
SET	:	150 KV
FILM	:	Industrex C
DENSITY	:	2.0
DEVELOPER	:	D19b, 20 C, 5 r
SFD	:	50 cm
LEAD SCREENS	:	Front 0.1 mm
		Back 0.15 mm

Fig 4.5 An exposure chart

4.4.3 Exposure Chart Method

An exposure chart is a graph relating the exposure to the material thickness. An exposure chart is normally prepared for a particular X-ray set or a particular gamma ray source experimentally. Using these, radiography of more complicated castings can be done quickly and effectively. (1,2,3)

To prepare exposure charts for X-rays or gamma rays, following parameters must be kept fixed;

1) X-ray set(Kilovoltage-amperage)/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
8) Type of Filter

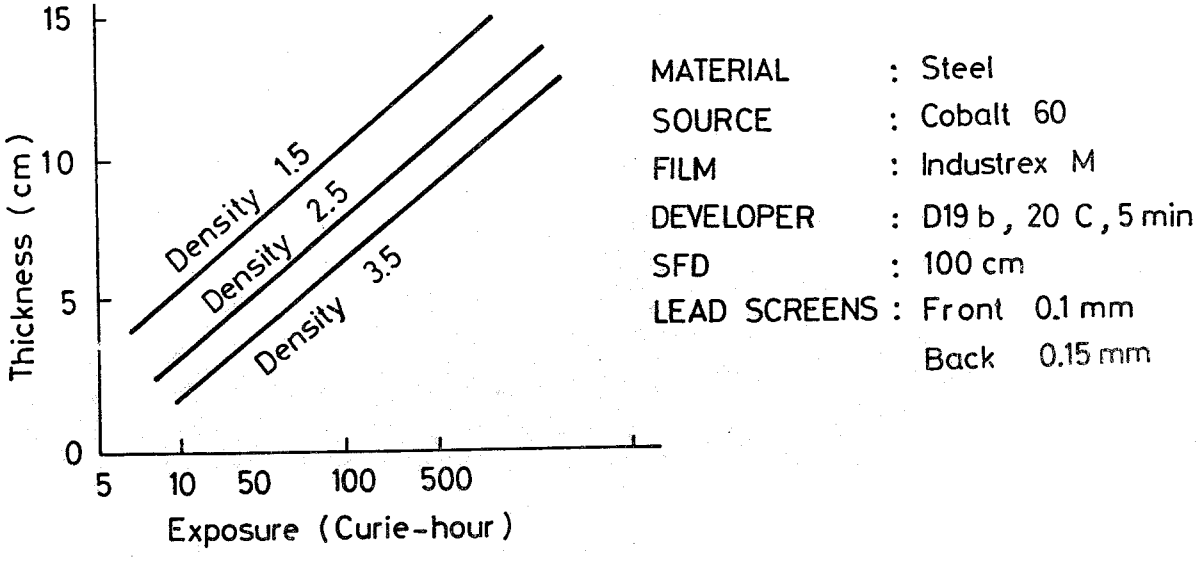


Fig 4.6 An Exposure Chart

4.4.4 Determination of Exposure Time by Experimental Method

Experimental method which is based on exposure chart technique can be explained by the following formula;

$$Q_1 . D_2^2 . h_1 = Q_2 . D_1^2 . h_2 \qquad (4.10)$$

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 the exposure chart,

D_2 = SFD to be used in the radiography,

h_1 = Exposure time used in preparing the exposure chart,

h_2 = Calculated exposure time for a required specimen thickness.

There are other factors that affect the exposure time determinations. These are summarized as follows;

1) Density of the film: These formulas and exposure charts are generally designed to give a radiographic density of 2.00. If the required density is different from the density indicated on the exposure chart, a film density factor (FDSFA) should be added to eq. 4.10 to correct this difference in the film densities.(3)

2) Film speed factor: Radiographic films consist of a thin transparent plastic sheet coated on one or both sides with an emulsion of gelatin, approximately 0.025 mm thick, containing very fine grains of silver bromide. Depending on the thickness of the grains, the films have different

speeds of resolution. The films with smaller grains need more exposure time than the ones with greater grains of silver bromide, but definition is much better in slow films.

Since radiographic films have different speed factors depending on their structure, if the film to be used has a different speed than the film used in preparing the exposure chart, a film factor, (F), should be taken into account.

Using these factors, the new formula becomes;

$$h_2=Q_1 . D_2^2 . h_1 . FDSFA . F/(Q_2 . D_1^2) \qquad (4.11)$$

4.4.5 Theoretical Method

Theoretical method defines the film density as the relative amount of visible light from an incandescent lamp that is transmitted through the radiograph as detected by a photomultiplier tube. (2) The film density is formulated as;

$$D=\log_{10}(J_o/J) \qquad (4.12)$$

where;

J_o : The visible light intensity without radiograph between the light source and the photo-multiplier tube,

J : The visible light intensity that passes through the radiograph at the point of interest,

The amount of visible light 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:

$$da/dt=K_1 . I(A-a) \qquad (4.13)$$

where;

a = The amount of reduced silver (q)
t = Elapsed exposure time (s)
K_1 = The efficiency of the film for the radiation being used; a constant
I = Radiation intensity (dis/sec)
A = Total amount of silver initially present in the film that can be reduced (q)

The solution to Eq 4.13 for a initially zero is;

$$a=A.(1-\exp(K_1 . I.t)) \qquad (4.14)$$

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

$$J_o/J=\exp(-K_2 . a) \qquad (4.15)$$

where, K_2 is a constant.

The film density for a given case, can be employed as a function of the amount of exposure by substituting Eq. (4.14) into Eq. (4.15) and substituting the subsequent equation into Eq. (4.13).

$$D=\log_{10}(\exp(-K_2 . A.(1-\exp(-K_1 . I.t)))) \qquad (4.16)$$

Since $\ln x = 2.303 \log_{10} x$

$$D = \ln\{\exp[-K_2 . A . (1-\exp(-K_1 . I . t)]\})/2.303$$

$$D = \frac{-K_2 . A . [1-\exp(-K_1 . I . t)]}{2.303} \qquad (4.17)$$

Defining a new constant K_3 as $-K_2 . A/2.303$;

$$D = K_3 . [1-\exp(-K_1 . I . t)] \qquad (4.18)$$

If this is solved for the amount of exposure;

$$I . t = -\ln(1-D/K_3)/K_1 \qquad (4.19)$$

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

$$I = \frac{S . \exp(-\psi . x)}{4 . \pi . (d1+d2)^2} \quad \text{dis/sec/cm}^2 \qquad (4.20)$$

where,

S = Source activity (dis/sec)

ψ = Absorption coefficient for the source and specimen (cm^2/g)

x = Specimen density thickness (g/cm^2)

d1= Source to specimen distance (cm)

d2= Specimen to film distance (cm)

Substituting Eq. (4.20) for I in Eq (4.19) and solving for t gives;

$$t = \frac{-\ln(1-D/K_3 . 4\pi . (d1+d2)^2 . \exp(\psi . x)}{K_1 . S} \qquad (4.21)$$

When $f(D) = -(4.\Pi/K_1).\ln(1-D/K_3)$ is substituted:

$$t = \frac{f(D).(d1+d2)^2.\exp(\psi.x)}{S} \qquad (4.22)$$

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 given in Appendix IV.

Scattered radiation causes an overexposure on films. Build up factors or effective absorption coefficients, (EAC), should be used to compensate for the scattered radiation. (1)

Table 4.1 Effective absorption coefficients for radiographic sources

Source	Effective absorption coefficient, cm^2/gr
Co-60	0.035
Cs-137	0.042
Ir-192	0.046
Ra-226	0.039

4.4.6 Determination of Exposure Time by Alternative Method

Alternative Method (6) is one that is improved by adding the build up factors into the Theoretical Method. The build up factors are used to increase the flexibility

of the Theoretical Method. The main difference between two methods is that the Alternative Method uses the linear absorption coefficients (LAC), but the other one takes advantage of the effective absorption coefficient (EAC) and tries to compensates the effect of build up factor. This compensation is not absolute, since EAC's are constant for all material thicknesses, although build up factors are variable for all materials, thicknesses and source energies.

Build up factors can be explained with the attenuation of radiation. The equation defining the attenuation of radiation by an absorber is that:

$$J = J_o . B . \exp(-\psi . x) \qquad (4.23)$$

where,

J_o = Intensity of incident radiation
J = Intensity of transmitted radiation
ψ = LAC for the special material
B = Build up factor

For the narrow beam case, the built up factor is equal to 1.00, but in radiography, the conditions usually fail to meet these ideal conditions; the sources of radiation may not be approximate points, the beam is wide and broad and thick absorbers are used. Therefore, taking these into consideration, a correction must be made on the time determination formula;

$$t = \frac{f(D) . SFD^2 . \Sigma_{i=1}^{n} [\exp(\psi . x)/B]}{S} \qquad (4.24)$$

where,

f(D) = A film factor (cm^{-2})

SFD = Source to film distance (cm)

x = Specimen density thickness (g/cm^2)

μ = Linear absorption coefficient (cm^{-1})

B = Build up factor

S = Source activity (dis/sec)

Alternative Method gives the results with minimum deviation among the exposure time determination methods, but since it needs computer application, it cannot be considered as a practical one. In this work, an alternative method was taken as a starting point.

5. EXPERIMENTAL WORK

The most important part of the study is totally devoted to experimental work, which was performed at the industrial application laboratories of Çekmece Nuclear Research and Training Center, Bogaziçi University and Technical University of Istanbul. A Cobalt-60 source with the activity of 7.52 Ci was used as a gamma ray source. The source was shielded in depleted Uranium. An X-ray tube with a range of 300 KV's and 5 miliamperes was also used in the second part of the experiments. The films were developed and density of the radiographs were measured by a microdensiometer.

The main aim of all this experimental work is to evaluate a time determination method for a system with two different media. For example, if a specimen is under a column of water or oil, how can it be radiographed under these conditions and how can the exposure time be determined? This situation might be observed in industrial systems, especially in on site inspection. If pipelines or any kind of pipe systems are considered, one can easily see that systems with two different media are not rarely encountered in industrial applications.

Before starting the experiments using alternative method, the time to reach 2.00 density in the presence of a second medium was calculated.

$$t = \frac{f(D).(sfd)^2.[\exp(\psi 1.x1.d1)/b1+\exp(\psi 2.x1.d1)/b2)].t(D)}{Sx3.7x10^{10}x60} \qquad (5.1)$$

where,

t = exposure time in minutes
f(D)= film factor
$\psi 1$ = linear absorption coefficient at energy E1
$\psi 2$ = linear absorption coefficient at energy E2

b1 = build up factor at energy E1
b2 = build up factor at energy E2
x1 = thickness of the specimen in cm
d = density of the specimen in gr/cm^3
S = activity of the source in Curies
t(D)= media factor

The evaluation of the second media as part of the specimen and a media factor are given as:

$$t(D)=\frac{\exp(\mu 3.x2.d2)+\exp(\mu 4.x2.d2)}{2} \qquad \text{(Eq. 5.2)}$$

where,

$\mu 3$= linear absorption coefficient at energy E1
$\mu 4$= linear absorption coefficient at energy E2
x2= height of the media
d2= density of the media

The build up factors are ignored in this formula.

In the experiments, a plastic vessel which contains different absorbants, such as water and oil, is set on top of the specimen on the same side of radiation source. The conditions that the radiographs are taken under can be summarized as follows:

a) A Co-60 source with its camera system (Fig 5.1 and 5.2) is used.
b) D7 films are used (f(D)= 1.6x10^{10} cm^{-2})
c) Back and rear Pb screens are used (their thicknesses are around 100μm)
d) The exposure time was kept constant during all radiographs. It was 19 min. for the Co-60 experiment.
e) The thickness of the sample was 35 mm.

f) An extra filter of 1 mm. thickness is also used.
g) Two different kinds of penetrameters are used; steel wires between 3-2.2 mm of thickness and aluminium ladder type

After the blank radiograph (without water or oil), other radiographs were taken by increasing medium height (starting with 5 cm., varying with increaments of 5 cm.). The densities of radiographs were measured by using a microdensiometer.

Densities of the films were plotted vs the height of the medium. Using the least squares method and the simplex method, the equation of the curve was obtained.

The exposure time required to reach 2.00 density for each case was calculated by the computer program "Correct.bas". (See Appendix III). The exposure time vs the height of the medium were plotted. The same procedure was repeated again and all of the formulas were obtained in the form of $y=A.\exp(B.x)$. The alternative formula was corrected in this way.

The second part of the experiments was performed by using an X-ray tube as the radiation source. The working conditions can be summarized as;

a) An X-ray tube was used.
b) D-7 (Agfa-Geavart) films with front and back Pb screens (125μm) were used.
c) 125 KV was applied to the tube under 3mA.
d) The exposure time which was determined by using the special exposure chart of the X-ray tube was kept constant during the radiographic experiments.
e) The sample thickness was 5 ± 0.5 mm

At first, a blank radiograph was taken under the empty vessel. After that eight other radiographs with varying heights of water were taken. The films were developed and

the densities were measured. The relations between film density and the height of the medium and between the exposure time required for 2.00 density and the height of the medium were formulated by the simplex method, same as the gamma ray experiment.

After the experimental part of the study was completed, the computer programs which had been prepared according to the alternative method were modified. A table displaying medium factors vs the height of medium was also prepared. Using this table, it is possible to correct exposure time in case of a second medium by just multiplying it by the medium factor "t(d)"

Although experiments were performed with only Co-60 and X-rays, the results for all radioisotopes used in practical application were included in the tables. The necessary constants were obtained from the mass absorption coefficients of water for various energies. The deviation between the experimental results of Co-60 and the theoretical results of other isotopes as the height of the medium increases shows the importance of build up factors.

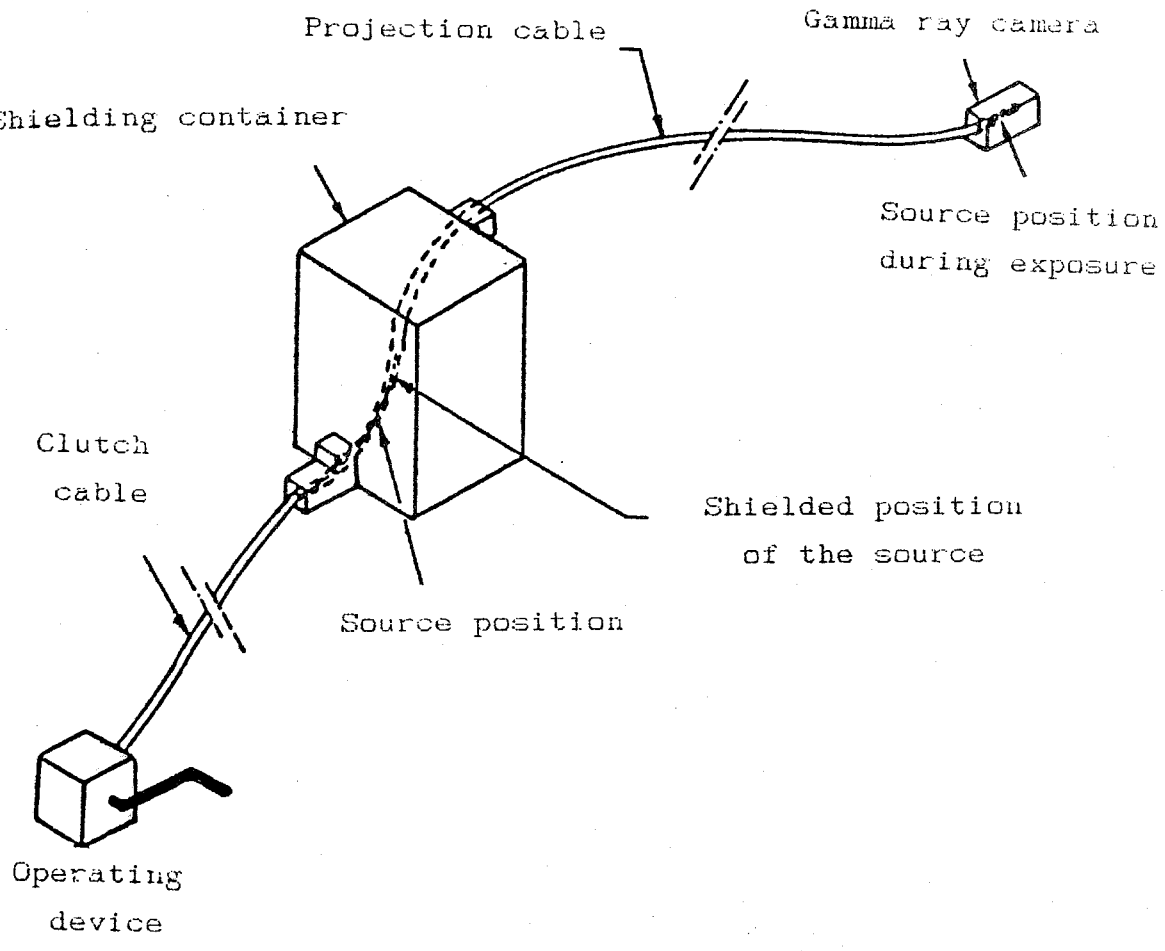


Fig 5.1 A Typical Gamma Ray Set

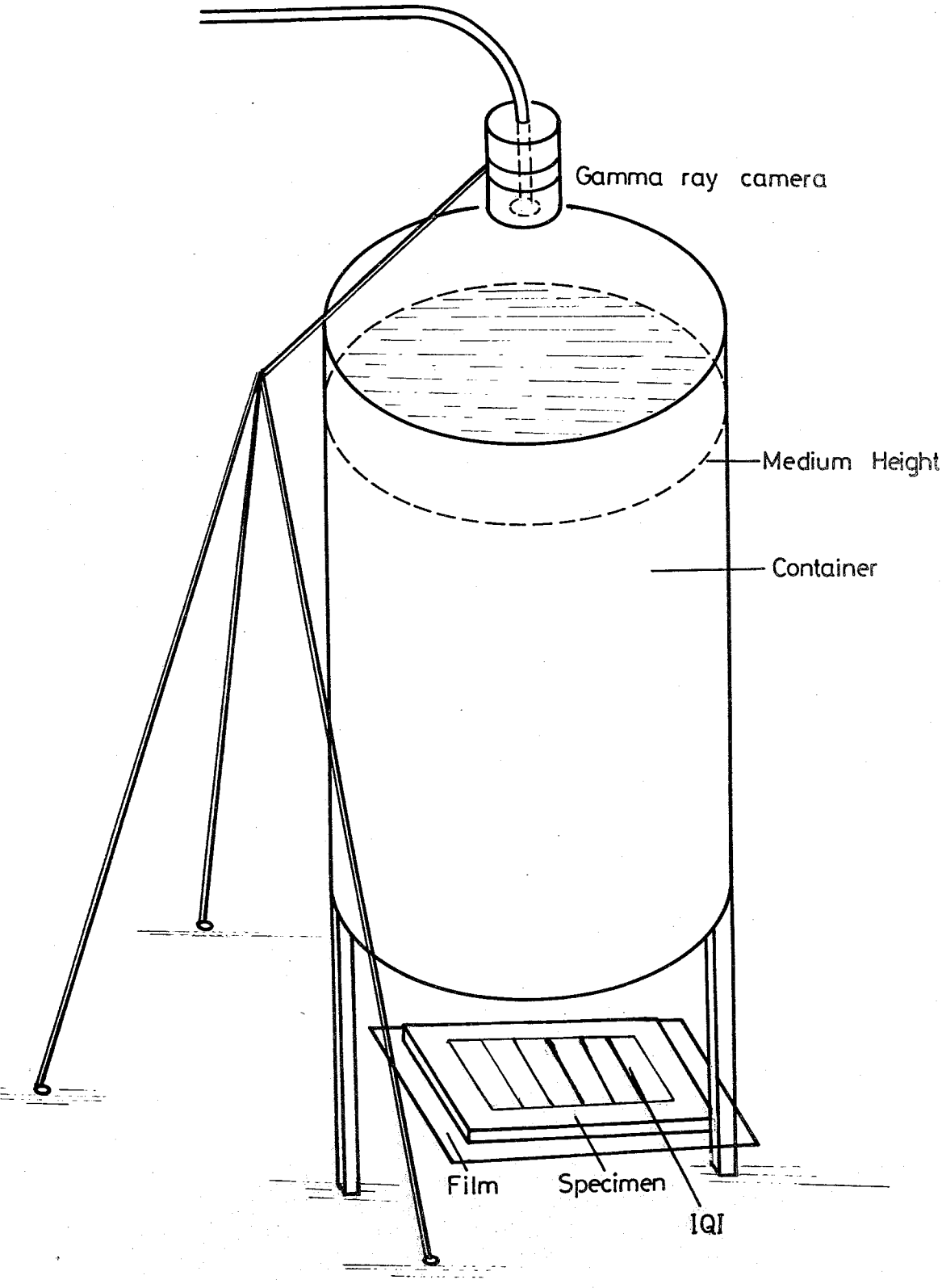


Fig 5.2 Experimental Set up

6. RESULTS

The experimental results showed that the density of the radiographs decreased with a factor of 3.96 by increasing water column up to 50 cm in case of Co-60 as it is seen from Table 6.1. An exponential decrease was expected according to the final simplex at the bottom of the page; on the other hand, 50 cm of oil column caused the radiograph density diminish by a factor of 3.67 as it is observed in Table 6.2. It was also predictable since oil density is a little bit lower than water density, the lowering effect of oil on film density is less than that of water. The effect of water column on the radiograph density in case of X-rays was greater than the other cases since X-rays are less energetic than gamma rays. The lowering factor was 5.56 in this case.(see Table 6.3)

The effect of increasing medium height on exposure time for a certain film density was also a exponential increase as expected. In Table 6.4 it can be observed that the exposure time was increased by a factor of 6.05 under a water column of 50 cm's. In the oil case this factor was 5.35 as shown in Table 6.5. The importance of medium density can be seen again; water with a higher density than oil has increased the required exposure time more than oil did. The increasing medium had a drastic effect on exposure time in case of X-rays, increasing it by a factor of 8.68 as shown in Table 6.6. This phenomenon is explained by the energy difference between X-rays and gamma rays.

Through Fig 6.1 to 6.6 the graphics of the results are presented. Also in Fig 6.7 (a) a radiograph taken by X-rays without a second medium can be seen. Other radiographs taken under increasing medium heights are shown in Fig 6.7(b) through Fig 6.7(f).

Table 6.1

HEIGHT OF WATER COLUMN VS DENSITY OF RADIOGRAPHS

(Using Co-60 source)

height of water (cm)	density (experimental)	density revised by lsm	density revised by simplex	standard deviation
0	2.02	2.221	2.173	-1.5656E-01
5	1.91	1.910	1.888	2.1694E-02
10	1.77	1.640	1.638	1.3177E-01
15	1.63	1.410	1.421	2.0874E-01
20	1.25	1.210	1.233	1.6966E-02
25	1.03	1.040	1.069	-3.9734E-02
30	0.76	0.890	0.928	-1.6806E-01
40	0.66	0.660	0.699	-3.8519E-01
50	0.51	0.480	0.526	-1.5751E-02

The final equation is $y=2.18\exp(-0.0284.x)$

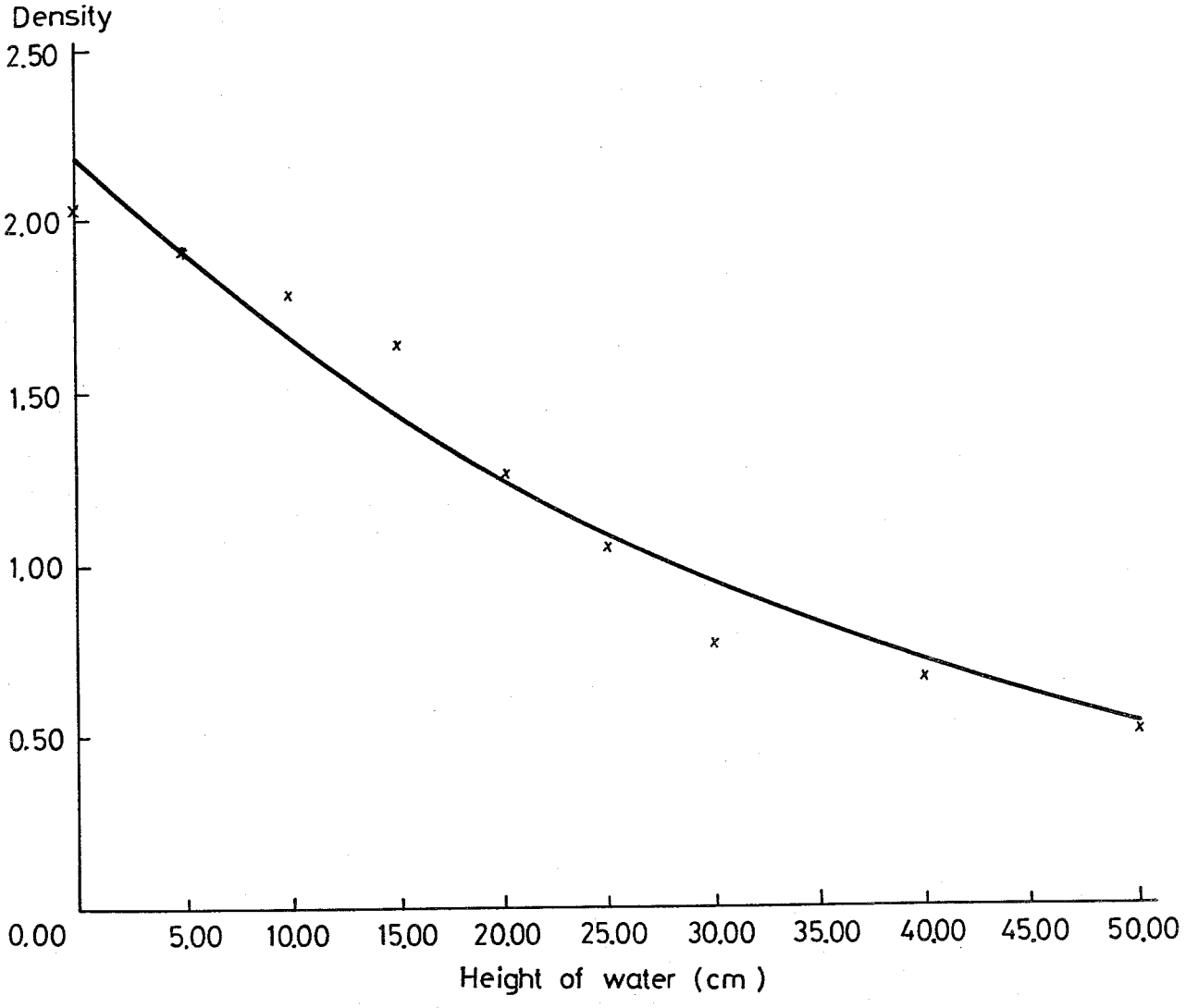


Fig 6.1

HEIGHT OF WATER COLUMN VS DENSITY OF RADIOGRAPHS

(Using Co-60 source)

Table 6.2

HEIGHT OF OIL COLUMN VS DENSITY OF RADIOGRAPHS

(Using Co-60 source)

height of oil (cm)	density (experimental)	density revised by lsm	density revised by simplex	standard deviation
0	2.02	2.210	2.158	-1.3860E-01
5	1.97	1.920	1.888	8.1937E-02
10	1.66	1.660	1.651	8.5688E-03
15	1.57	1.440	1.444	1.2554E-01
20	1.36	1.250	1.263	9.6578E-02
25	1.14	1.080	1.105	3.4924E-02
30	0.81	0.940	0.966	-1.5658E-01
40	0.67	0.700	0.739	-6.9476E-02
50	0.55	0.520	0.566	-1.5733E-02

The final equation is $y=2.16.\exp(-0.0268.x)$

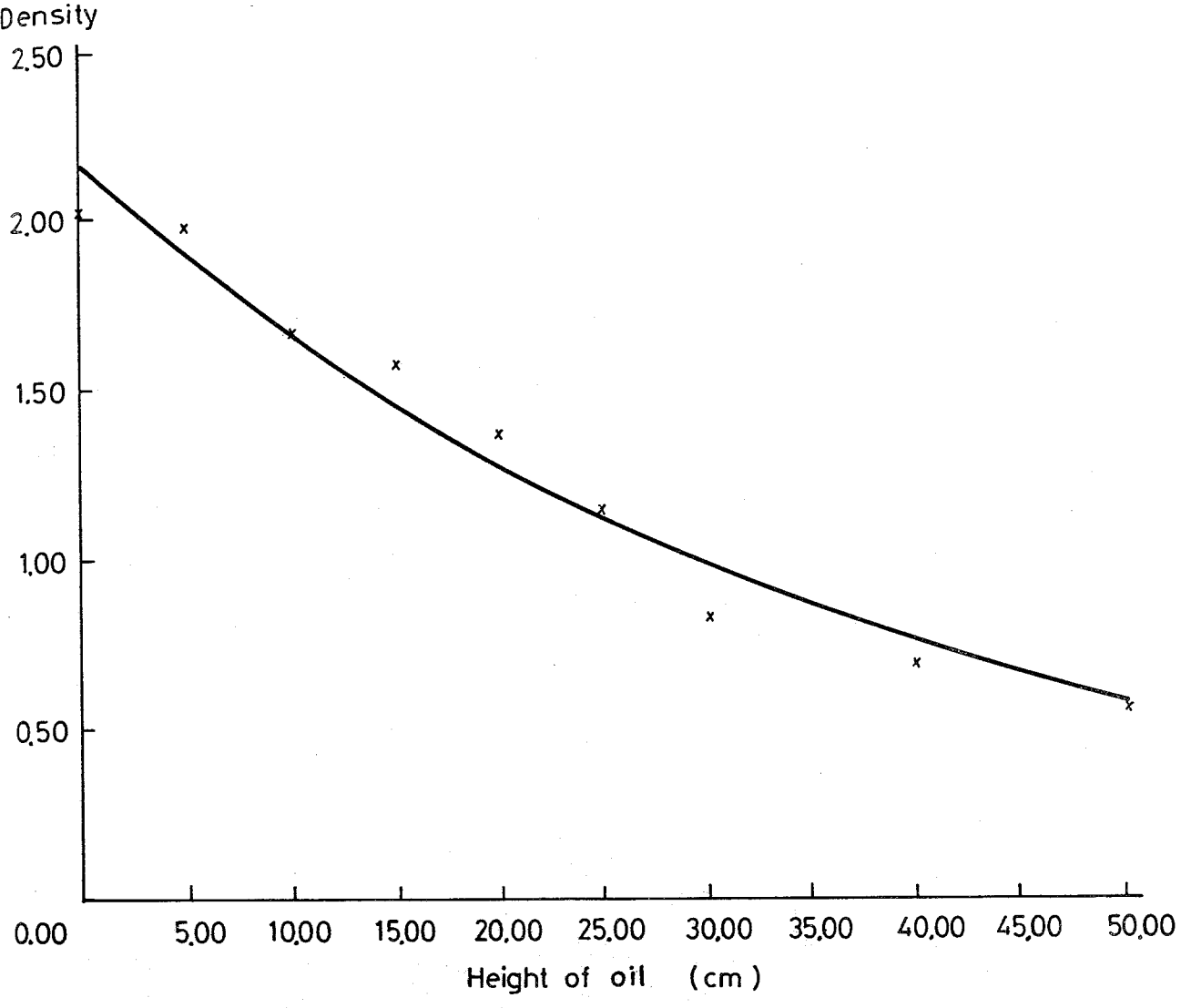


Fig 6.2

HEIGHT OF OIL COLUMN VS DENSITY OF RADIOGRAPHS

(Using Co-60 source)

Table 6.3

HEIGHT OF WATER COLUMN VS DENSITY OF RADIOGRAPHS

(Using X-rays)

height of water (cm)	density (experimental)	density revised by lsm	density revised by simplex	standard deviation
0	2.00	1.954	2.017	-1.7202E-02
3	1.56	1.501	1.526	3.3669E-02
6	1.21	1.153	1.155	5.5090E-02
9	0.76	0.886	0.874	-1.1387E-01
15	0.51	0.523	0.500	9.6817E-03
20	0.36	0.337	0.314	4.5651E-02

The final equation is $y=2.02.\exp(-0.0924.x)$

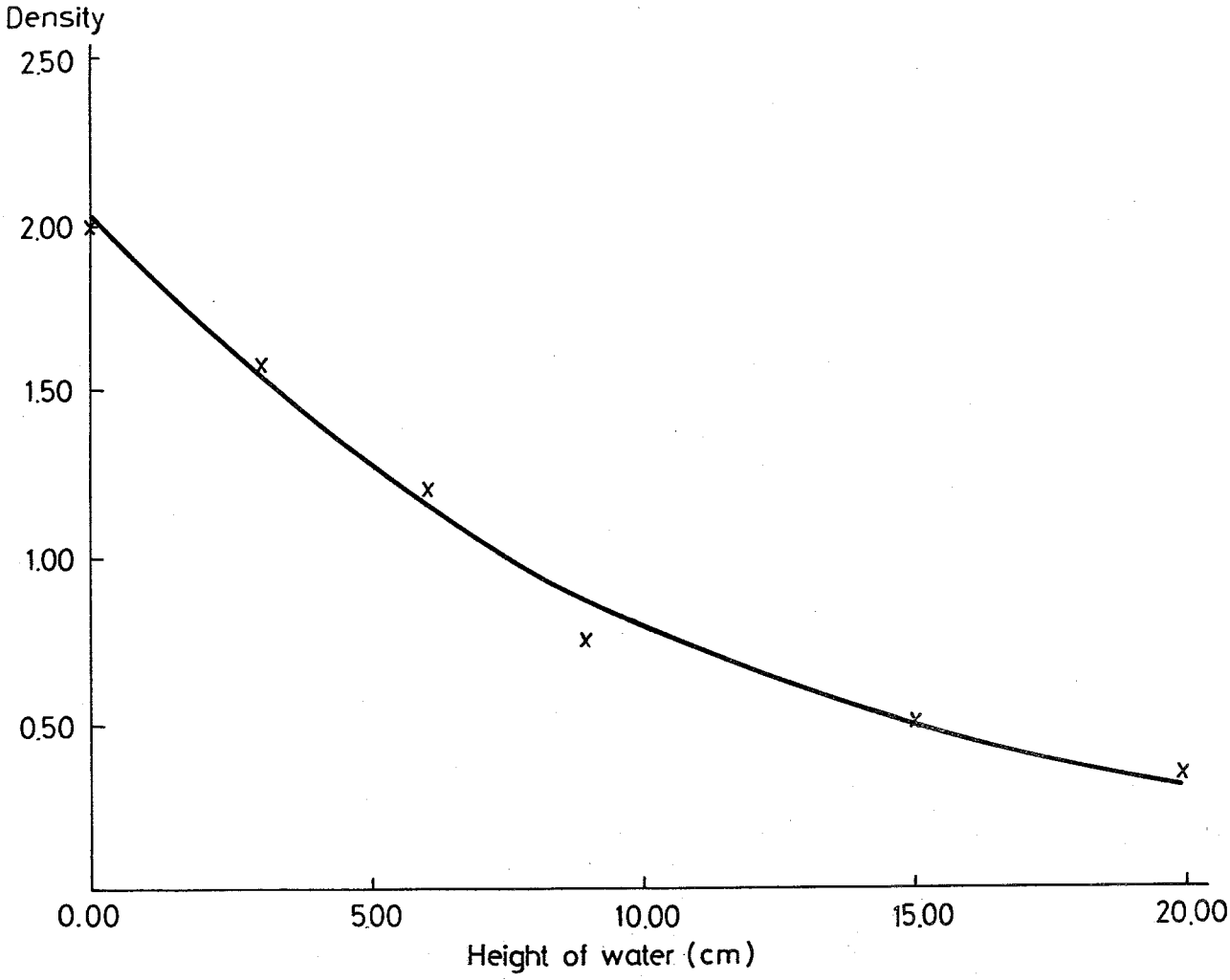


Fig 6.3

HEIGHT OF WATER COLUMN VS DENSITY OF RADIOGRAPHS

(Using X-rays)

Table 6.4

HEIGHT OF WATER COLUMN VS EXPOSURE TIME FOR 2.00 DENSITY

(Using Co-60)

height of water (cm)	exp. time (experimental) (min)	exp. time revised by lsm	exp.time revised by simplex	standard deviation
0	19.00	16.20	16.449	2.5500E-00
5	20.05	19.71	19.999	5.3763E-02
10	21.92	23.98	24.308	-2.2880E-00
15	24.19	29.15	29.548	-5.3590E-00
20	33.33	35.48	35.919	-2.5899E-00
25	42.52	43.16	43.664	-1.1444E-00
30	63.25	52.50	53.078	1.0171E+01
40	77.11	77.69	78.434	-1.3243E-00
50	114.87	114.97	115.902	-1.0321E+00

The final equation is y=16.44.exp(0.0391.x)

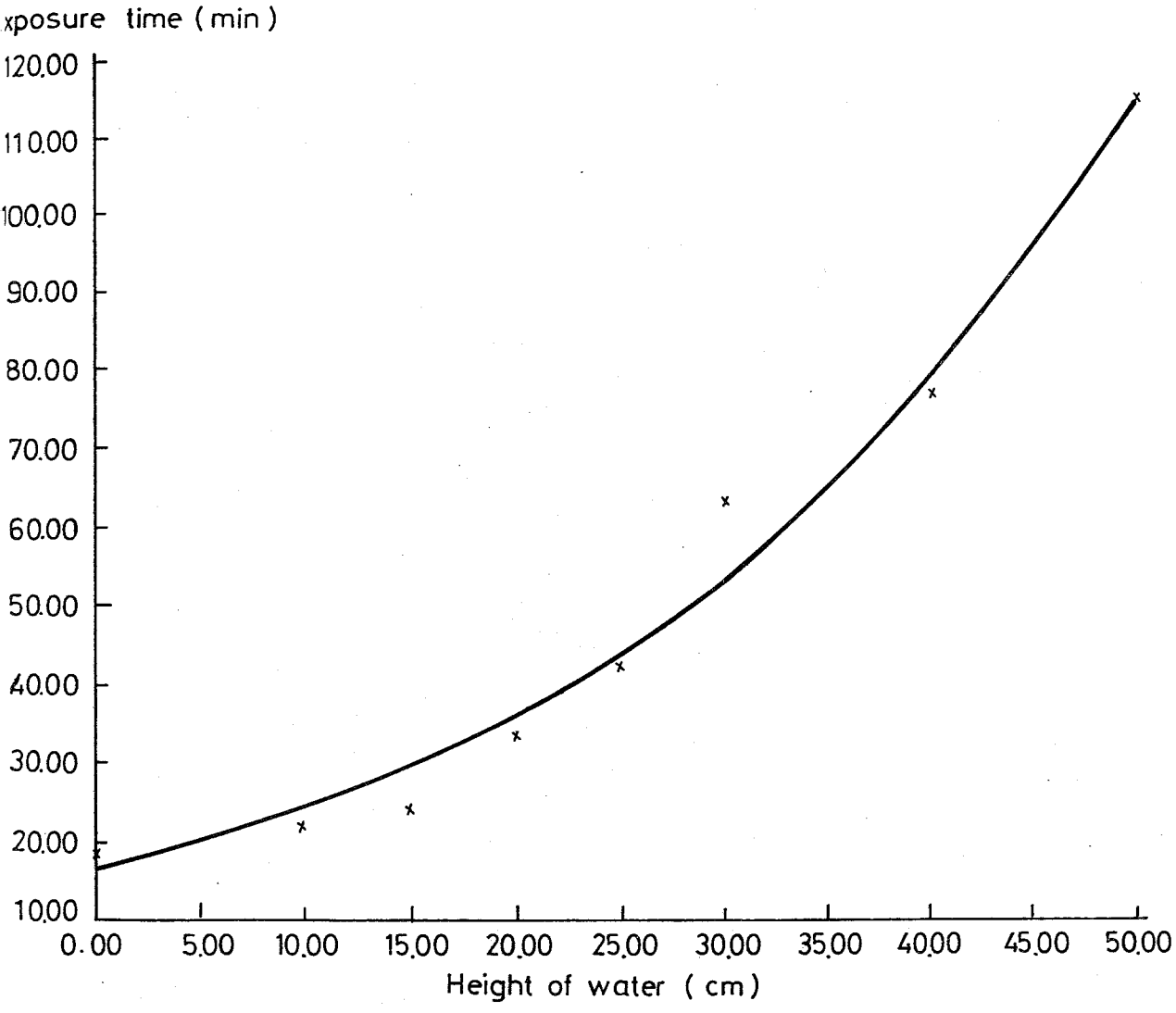


Fig 6.4

HEIGHT OF WATER COLUMN VS EXPOSURE TIME FOR 2.00 DENSITY

(Using Co-60)

Table 6.5

HEIGHT OF OIL COLUMN VS EXPOSURE TIME FOR 2.00 DENSITY

(Using Co-60)

height of oil (cm)	exp. time (experimental) (min)	exp. time revised by lsm	exp. time revised by simplex	standard deviation
0	19.00	16.42	16.448	2.5100E+00
5	19.34	19.42	19.825	-4.8462E-01
10	23.67	22.99	23.837	-1.6748E-01
15	25.31	27.20	28.663	-3.3526E+00
20	30.08	32.18	34.464	-4.3844E+00
25	37.37	38.08	41.441	-4.0707E+00
30	58.03	45.06	49.829	8.2010E+00
40	75.46	63.09	72.043	3.4167E+00
50	101.60	88.34	104.161	-2.5610E+00

The final equation is $y=16.49.\exp(0.0369.x)$.

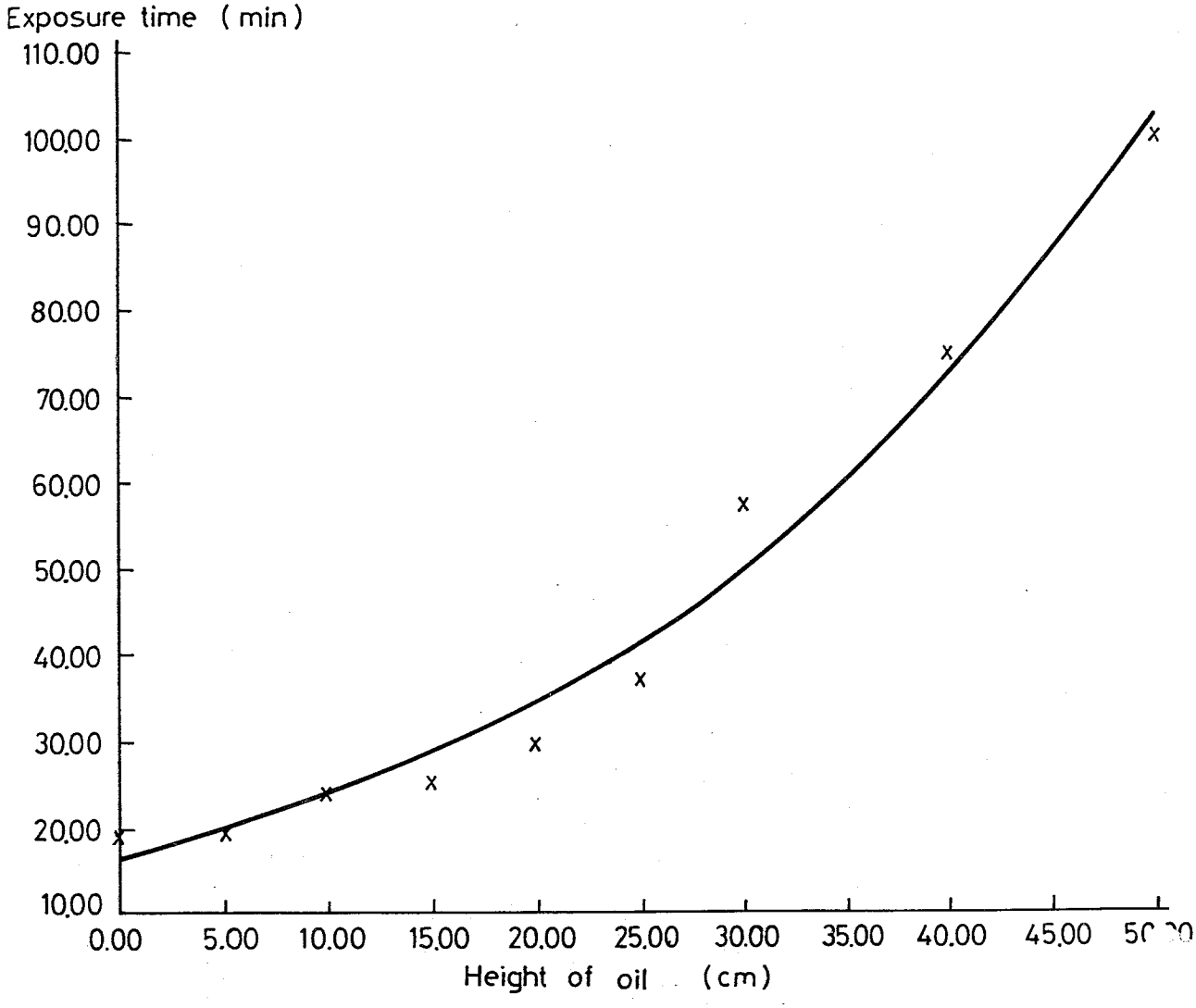


Fig 6.5

HEIGHT OF OIL COLUMN VS EXPOSURE TIME

FOR 2.00 DENSITY

(Using Co-60)

Table 6.6

HEIGHT OF WATER COLUMN VS EXPOSURE TIME FOR 2.00 DENSITY

(Using X-rays)

height of water (cm)	exp. time (experimental) (min)	exp. time revised by lsm	exp. time revised by simplex	standard deviation
0	3.33	3.365	4.088	-7.5858E-01
3	4.47	4.725	5.508	-1.0389E+00
6	6.08	6.636	7.422	-1.3427E+00
9	11.09	9.318	10.000	1.0886E+00
15	20.13	18.374	18.150	1.9727E+00
20	28.91	32.360	29.841	-9.3534E-01

The final equation is $y=4.09.\exp(0.0994.x)$

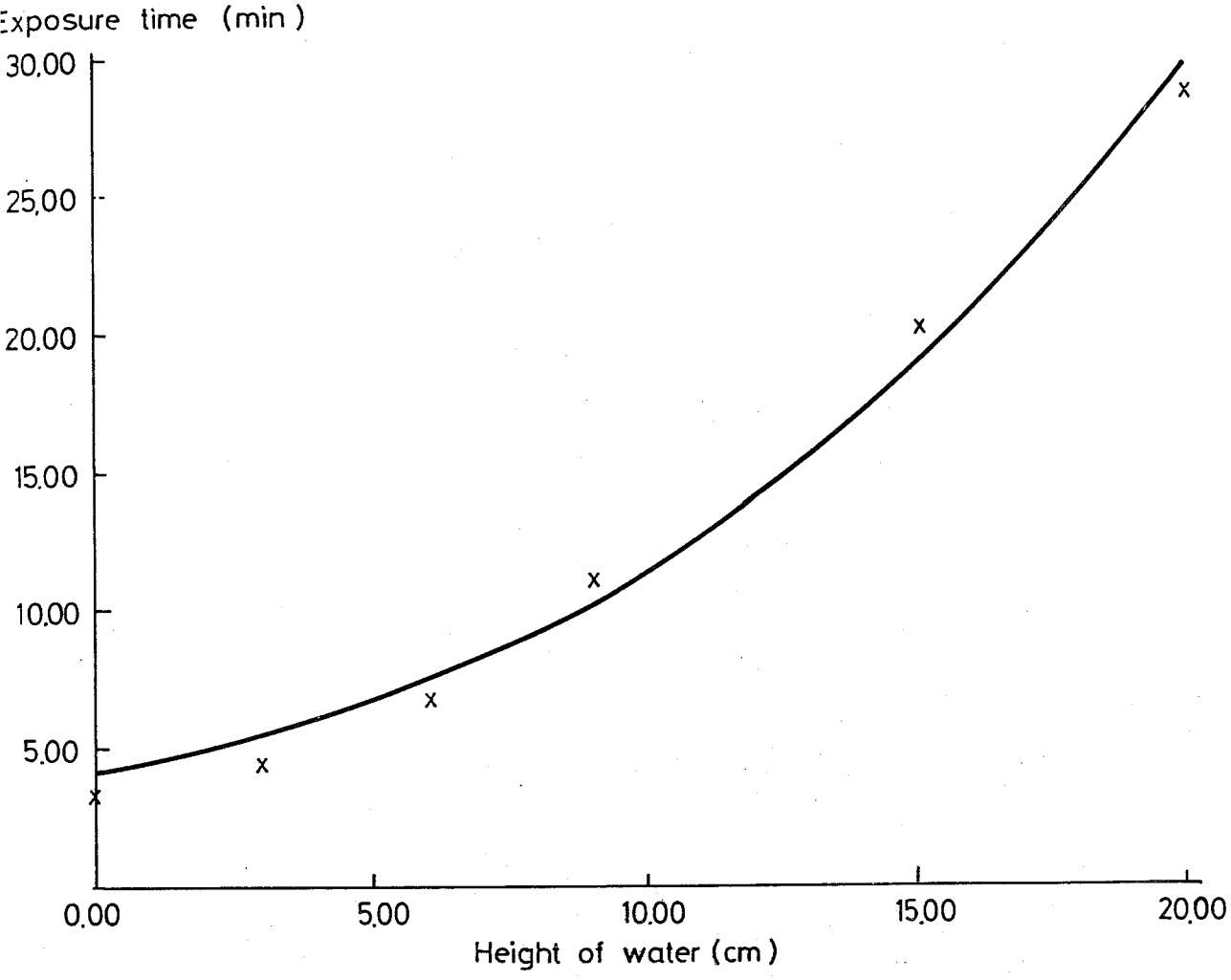


Fig 6.6

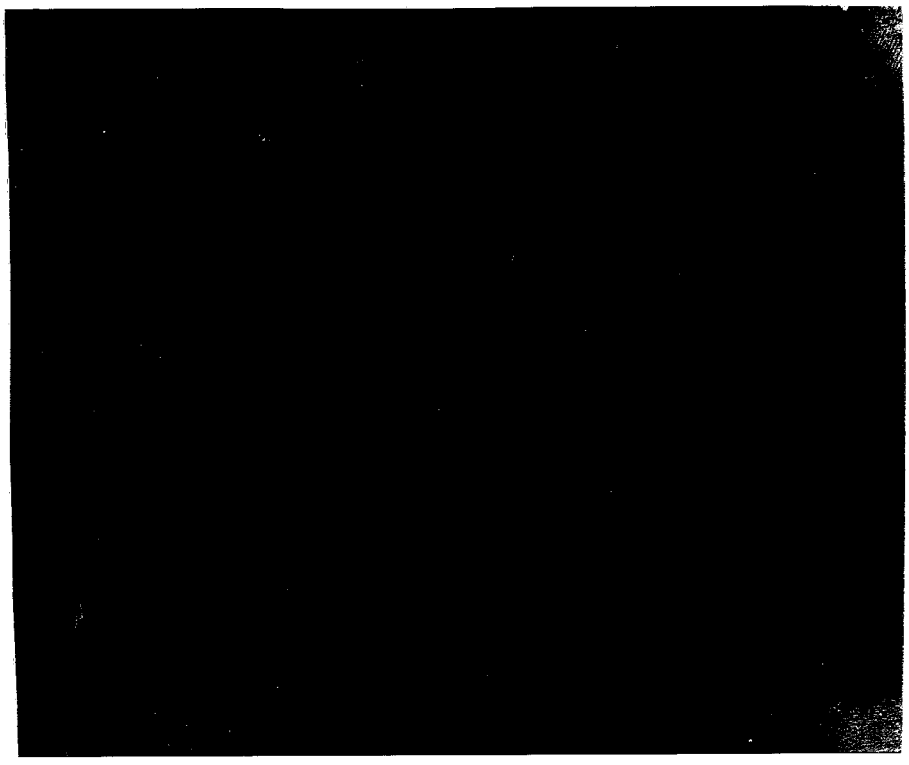
HEIGHT OF WATER COLUMN VS EXPOSURE TIME

FOR 2.00 DENSITY

(Using X-rays)

RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	1.71
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	0 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (a)

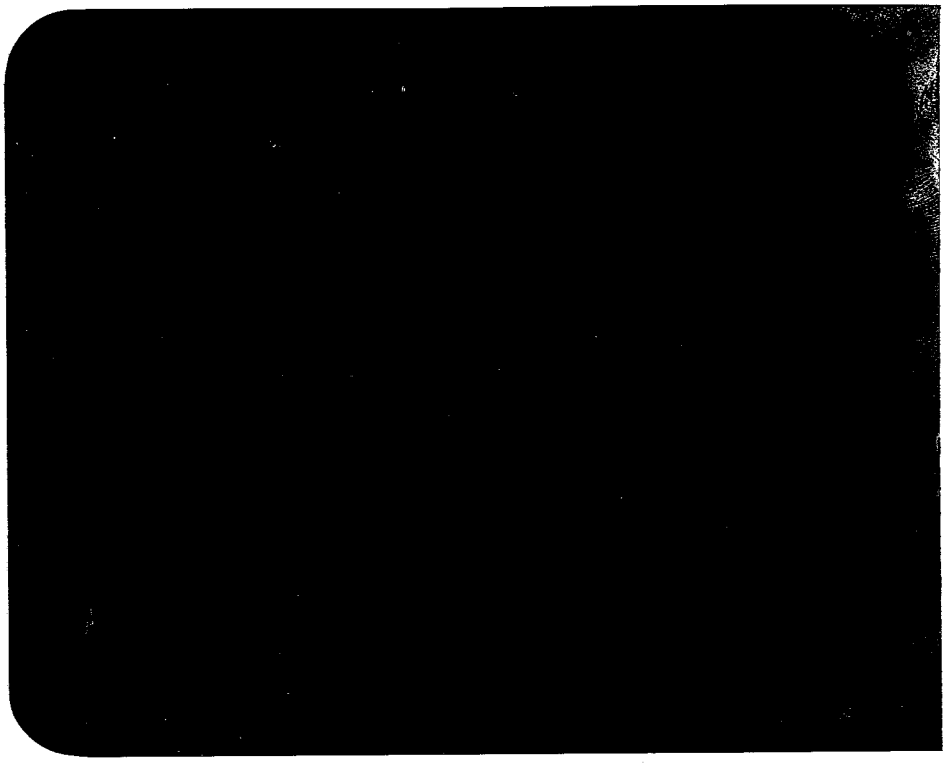


RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	1.71
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	0 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (a)

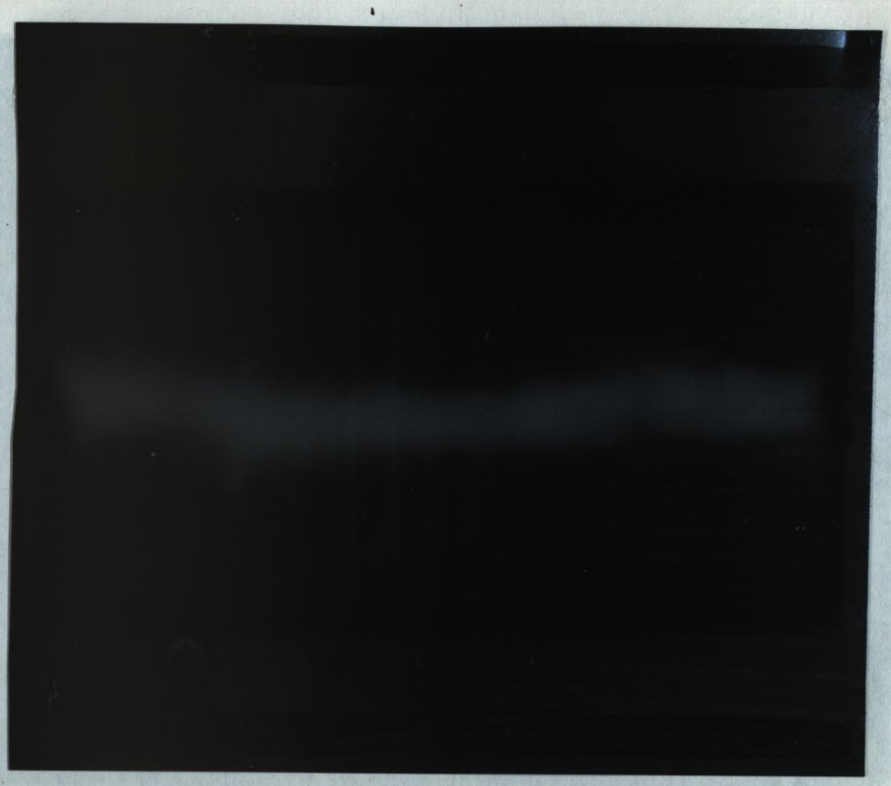
RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	1.30
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	3 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (b)



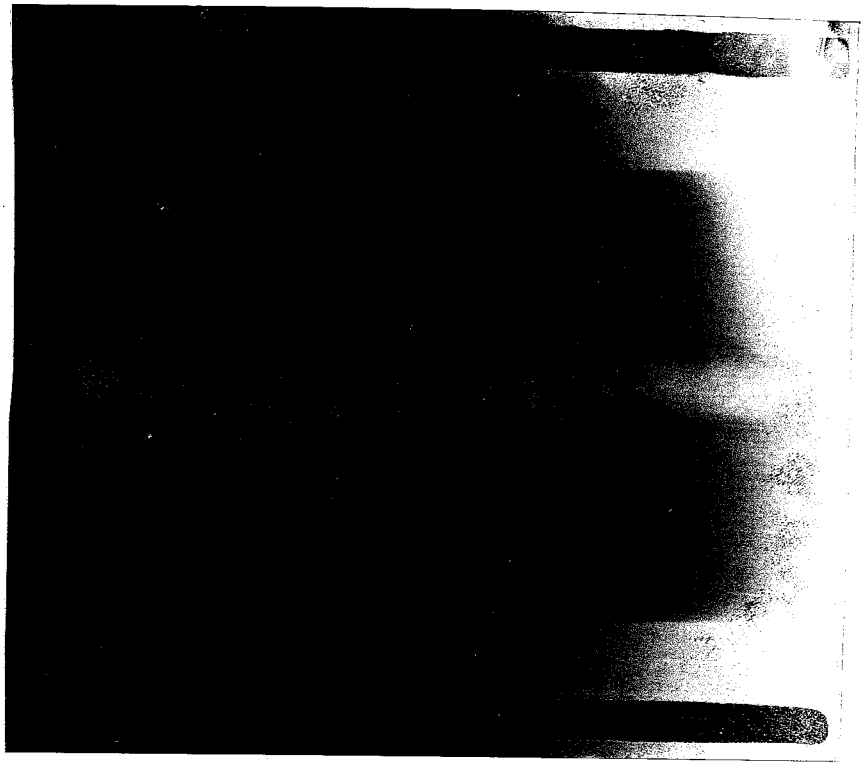
RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	1.30
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	3 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (b)



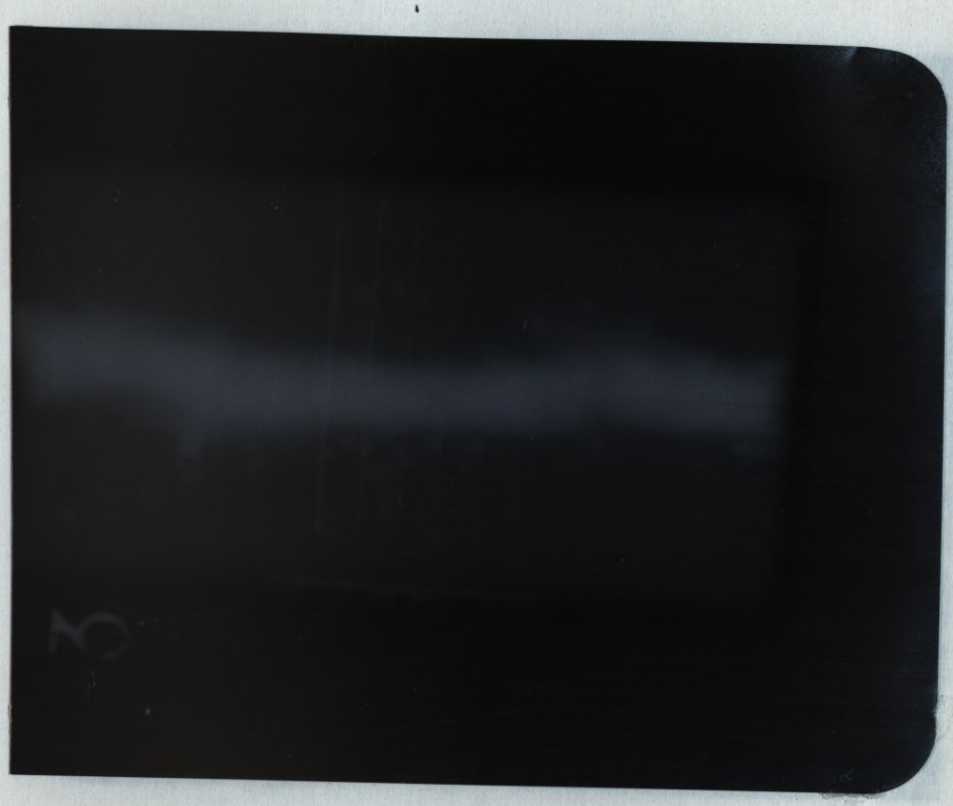
RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	1.02
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	6 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (c)



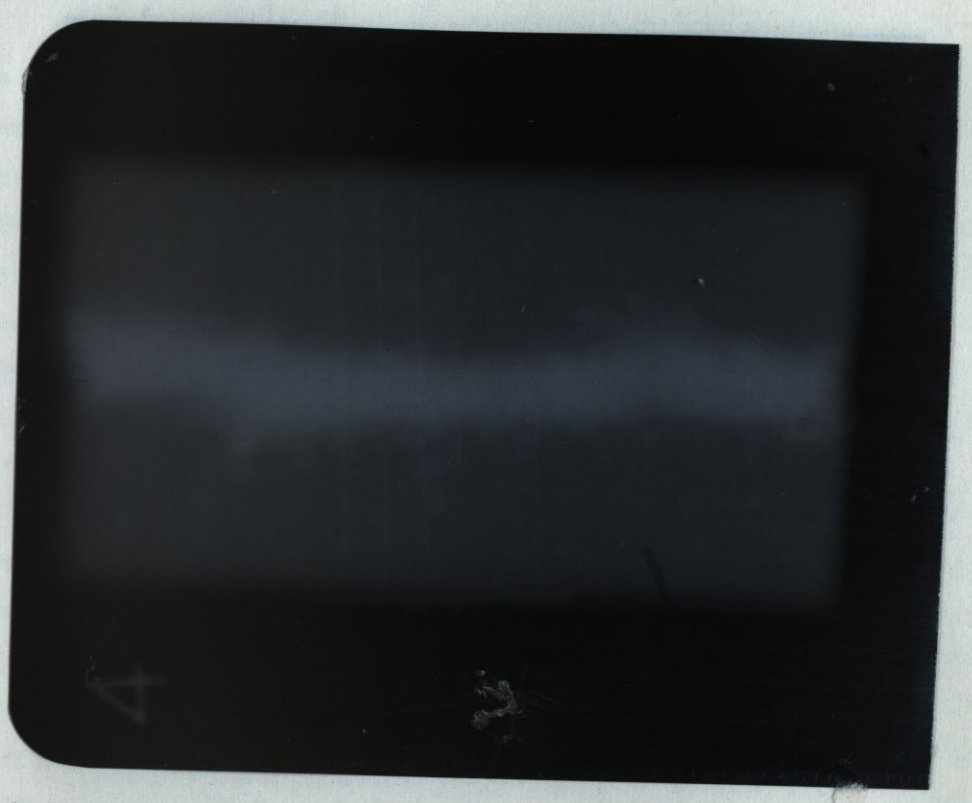
RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	1.02
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	6 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (c)



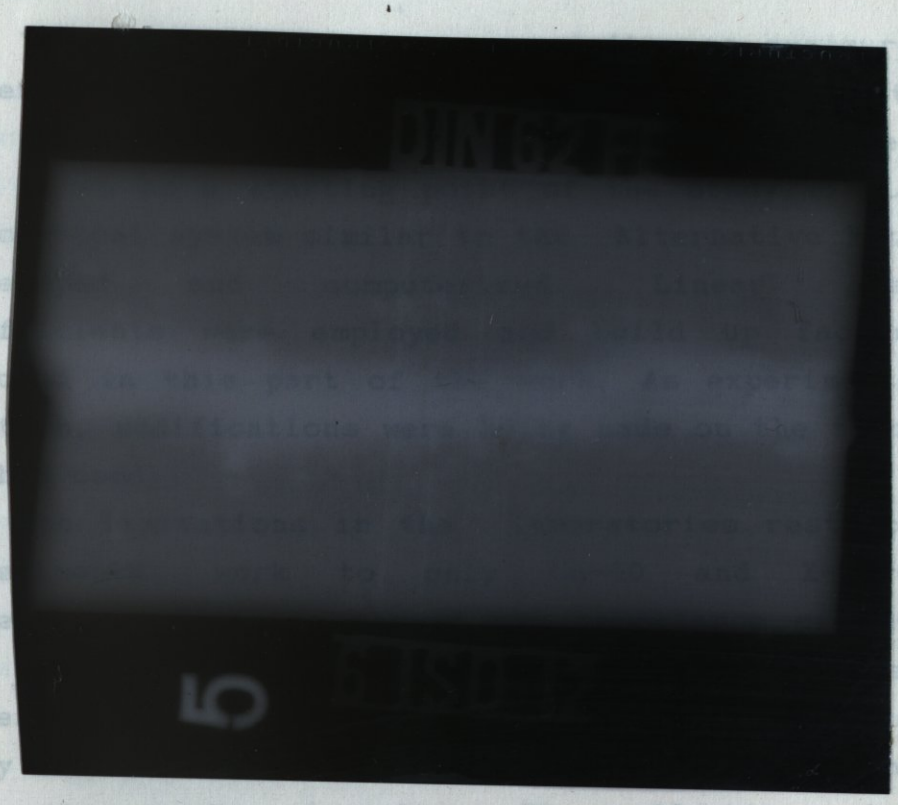
RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	0.64
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	9 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (d)



RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	0.43
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	15 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (e)



RADIOACTIVE SOURCE	:	X-Rays with 125 KV and 3mA
FILM TYPE	:	D7 (Agfa-Geavart)
FILM DENSITY	:	0.30
MATERIAL	:	Steel
THICKNESS	:	0.5 cm
MEDIUM	:	Water
MEDIUM HEIGHT	:	20 cm
EXPOSURE TIME	:	3 min 40 sec

Fig 6.7 (f)

7. CONCLUSIONS

The aim of the work was to define an exposure time determinatiom system for radiographic experiments with two different media at the beginning. Alternative method was taken as a starting point of the study.(6) Later, a theoretical system similar to the Alternative Method was developed and computerized. Linear absorption coefficients were employed and build up factors were ignored in this part of the work. As experimental work went on, modifications were being made on the theoretical method used.

The limitations in the laboratories restricted the experimental work to only Co-60 and X-rays. The experimental results showed the importance of the build up factors. As height of the medium increased the experimental results deviated from the theoretical ones very much since the build up factors had been ignored in the theoretical formulas. The effective absorption coefficients were used in order to cope with that; these were the constants that were obtained from the consideration of the experimental results.

The experimental results showed that the density of the radiographs decreased exponentially as the medium height increased; but, on the other hand the exposure time increased again exponentially under the increasing medium height. The water column decreased the density by a factor of 3.96 and increased the exposure time required for 2.00 density by a factor of 6.05 whereas the effect of oil column on these were by factors of 3.67 and 5.35. The main reason for this slight difference is the difference between densities of water and oil; water being more dense than oil absorbs radiation more, therefore affects density of radiographs more. The density of radiographs were affected the most in the X-

ray case since X-rays are less energetic than gamma rays; they were absorbed in water more than the gamma rays of Co-60.

As the last step, medium factor tables were prepared. The main point of consideration in this part is the practicalness of their usage. It is a well-known fact that mathematics or any kind of calculations are considered as a burden in practical applications. So the practicians can determine the exposure time for a certain case by the method they wish and later multiply the medium factor by that depending upon the height of the medium present.

The last remark will be that every exposure time determination system has an uncertainity in itself; this includes the method developed in this thesis also. The differences in experimental conditions and films used were the main reasons for this.

APPENDIX I

"THE MAIN COMPUTER PROGRAMS"

I. COMPUTER PROGRAM

I.1 The Function of the Program

A computer program determining the exposure time in different media was developed before starting with the experimental work. Essentially it was necessary to computerize the alternative method, since it is too complex to deal with calculators. The outputs of the program were used to compare the experimental and the theoretical results, so the computer program was improved by using the experimental results. Two versions of the program were introduced; one in BASIC and the other in FORTRAN.

The main program is written especially for the case of Co-60, but by changing the constants it can be used for any kind of radioactive isotope. This program takes advantage of the alternative method which gives the least deviation from experimental results.

Another program dealing with all radioactive isotopes used in practical application was also improved using the theoretical method. The incorporation of the theoretical method into this program was a necessity, since the build up factors of many radioactive isotopes for several materials are not known.

Although the programs were developed for 2.00 density, exposure times for other values can be obtained by using appropriate density factors. The phrase "out of scale" in the output means that the dimensions of the specimen are not appropriate for gammagraphy with that source.

I.2 Arrays and Variables Used in the Basic Version of the Main Program

Arrays:

1) b(i): Build up factors
2) y(i): Energy of the build up factors (Mev)
3) x(i): Thickness of the samples for build up factors (cm)
4) q(i): Build up factors after interplation
5) d(i): Energy of the radioisotopes (Mev)
6) m(i): Product of the density and linear absorption coefficient (g/cm^2)

Variables:

1) d1: Density of the material (g/cm^3)
2) A1: Linear absorption coefficient (cm^{-1})
3) A2: Linear absorption coefficient (cm^{-1})
4) x1: Thickness of the specimen (cm)
5) x2: Height of the medium (cm)
6) sfd: Source to film distance (cm)
7) s: Activity of the source (Curie)
8) f1: Film Factor (cm^{-2})
9) t(d): Medium factor
10) M : Medium type
11) t : Exposure time (min)
12) dt: Density factor

I.3 The Main Computer Program (Basic Version)

```
10 DIM m(4),i(4),d(4),Q(4),x(7),y(8),b(8,7)
20 DEF FNt(e1,e2)=e1*EXP(e2*x2)
30 d1=7.86
40 FOR h=1 TO 2:READ I(h):NEXT h
50 DATA .0551,0.0516
60 FOR i=1 TO 7
70 READ x(i)
80 DATA 1,2,4,7,10,15,20
90 NEXT i
100 FOR i=1 TO 7
110 FOR j=1 TO 8
120 READ b(j,i)
130 DATA 1.98,1.87,1.76,1.55,1.45,1.34,1.27,1.20
140 DATA 3.09,2.89,2.43,2.15,1.94,1.72,1.56,1.42
150 DATA 5.98,5.39,4.13,3.51,3.03,2.58,2.23,1.95
160 DATA 11.7,10.2,7.25,5.85,4.91,4.14,3.49,2.99
170 DATA 19.2,16.2,10.9,8.51,7.11,6.02,5.07,4.35
180 DATA 35.4,28.3,17.6,13.5,11.2,9.89,8.50,7.54
190 DATA 55.6,42.7,25.1,19.1,16.0,14.7,13.0,12.4
200 NEXT:NEXT
210 FOR k=1 TO 8
220 READ y(k)
230 NEXT k
240 DATA .5,1.0,2.0,3.0,4.0,6.0,8.0,10.0
250 d(1)=1.173:d(2)=1.332
260 INPUT "Type the name of the medium you used"; media$
270 IF media$="water" THEN e1=16.44/19:e2=0.03905:GOTO 300
280 IF media$="oil" THEN e1=16.49/19:e2=0.03687:GOTO 300
290 PRINT" NO MEDIUM ASSUMED"
300 INPUT "Enter the thickness of the specimen in cm ";x1
310 INPUT "Enter the height of the media in cm";x2
320 INPUT "Enter source to film distance in cm";sfd
330 INPUT "Enter the activity of the source in curies";s
```

```
340 INPUT "Enter the film factor";fd
350 M(1)=X1*I(1)*D1:M(2)=X1*I(2)*D1:M(3)=X2*I(3)*D2:M(4)=
    X2*I(4)*D2
360 M1=M(1):M2=D(1)
370 GOSUB 500
380 Q(1)=BL
390 m1=m(2):m2=d(2)
400 GOSUB 500
410 q(2)=b1
420 f1=FNt(e1,e2)
430 f2=EXP(m(1))/(q(1))+EXP(m(2))/(q(2))
440 t1=(fd*(sfd↑2)*f2)/(s*3.7E+10*60)
450 t2=t1*f1
460 PRINT USING " X1=####.### X2=####.###
    SFD=###.##";x1,x2,sfd
470 PRINT USING " expo. time (without medium)=####.## expo
    time( with medium)=#####.##";t1,t2
480 GOTO 260
490 END
500 IF m1<x(1) OR m1>x(7) THEN PRINT "out of scale":GOTO
    260
510 IF m2<y(1) OR m2>y(8) THEN PRINT "out of scale":GOTO
    260
520 FOR m=2 TO 7
530 IF m1<x(m) THEN I1=m:I2=m-1:GOTO 550
540 NEXT m
550 FOR n=2 TO 8
560 IF m2<y(n) THEN j1=n:j2=n-1:GOTO 580
570 NEXT n
580 u1=(x(I1)-m1)/(x(I1)-X(I2))
590 u2=b(j2,i1)-(b(j2,i1)-b(j2,i2))*u1
600 u3=b(j1,i1)-(b(j1,i1)-b(j1,i2))*u1
610 u4=(y(j1)-m2)/(y(j1)-y(j2))
620 b1=u3-(u3-u2)*u4
630 RETURN
```

I.4 Arrays and Variables Used in the Fortran Version of the Main Program

In the main part:

X1 : Specimen thickness (cm)
X2 : Medium height (cm)
D1 : Material density (g/cm^3)
D2 : Medium density (g/cm^3)
MU(I) : Mass absorption coefficient (cm^2/g)
SDF : Film to source distance (cm)
S : Source activity (Curie)
FD : Film factor (cm^{-2})
MUM(I): Mass absorption coef.*material density*material thickness
MEV : Energy (Mev)
DF : Density factor

In the subroutine:

DUM : μ*x
DEV : Energy (Mev)
LB : Build up factor
X(N) : Arrays for build up factor
Y(M) : Arrays for build up factor
B(M,N): Arrays for build up factor

I.5 The Main Computer Program (Fortran Version)

```
      PROGRAM EXPO (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION BL(4)
      REAL MEV(2),MUM(4),MU(2)
      DATA MU/0.0516,0.0516/
      DATA D1,D2,FD,DF/7.86,1.00,16.0E9,1.00/
      WRITE(6,28)
28    FORMAT('ENTER X1,X2,SDF,S')
      READ(5,10) X1,X2,SDF,S
10    FORMAT(4F7.3)
      MUM(1)=X1*MU(1)*D1
      MUM(2)=X1*MU(2)*D1
      CALL BUILD(MUM(1),MEV(1),BL(1))
      CALL BUILD(MUM(2),MEV(1),BL(2))
      WRITE(6,29)
29    FORMAT('ENTER 1 FOR WATER , 2 for OIL or 0 for NO
     *MEDIUM')
      READ(5,*)  T
      IF T=1 THEN
          E1=16.44/19
          E2=0.03905
      ENDIF
      IF T=2 THEN
          E1=16.49/19
          E2=0.03687
      ENDIF
      IF T=0 THEN
          E1=1
          E2=0
      ENDIF
      FAK1=E1*EXP(E2*X2)
      FAK2=EXP(MUM(1)/BL(1))+EXP(MUM(2)/BL(2))
      TIME1=FD*DF*(SDF*SDF)*FAK2/(S*3.7E+10*60)
      TIME=TIME1*FAK1
```

```
      WRITE(6,100) X1,X2,FAK1,TIME
  100 FORMAT(1H1,4X,'RADIOACTIVE SOURCE: CO-60',//,
     *           5X,'ACTIVITY          : 7.52 CURIE',//,
     *           5X,'FILM TYPE         : D7',//,
     *           5X,'FILM DENSITY      : 2.00',//,
     *           5X,'MATERIAL          : STEEL',//,
     *           5X,'THICKNESS         : ',F7.3,'CM',//,
     *           5X,'MEDIUM HEIGHT     : ',F7.3,'CM',//,
     *           5X,'MEDIUM FACTOR     : ',F7.3,//,
     *           5X,'EXP. TIME         : ',F7.3)
      END

      SUBROUTINE BUILD(DUM,DEV,LB)
      PARAMETER (N=7,M=8)
      REAL LB
      DIMENSION X(N),Y(M),B(M,N)
      DATA X/1,2,4,7,10,15,20/
      DATA B/1.98,1.87,1.76,1.55,1.45,1.34,1.27,1.20
     *       3.09,2.89,2.43,2.15,1.94,1.72,1.56,1.42
     *       5.98,5.39,4.13,3.51,3.03,2.58,2.23,1.95
     *       11.7,10.2,7.25,5.85,4.91,4.14,3.49,2.99
     *       19.2,16.2,10.9,8.51,7.11,6.02,5.07,4.35
     *       35.4,28.3,17.6,13.5,11.2,9.89,8.50,7.54
     *       55.6,42.7,25.1,19.1,16.0,14.7,13.0,12.4/
      DATA Y/ .5,1.0,2.0,3.0,4.0,6.0,8.0,10.0/
      IF(DUM.LT.X(1).OR DUM.GT.X(7)) GO TO 200
      IF(DEV.LT.Y(1) OR DEV.GT.Y(8)) GO TO 200
      DO 10 I=2,N
      IF(DUM.LT.Y(I)) THEN
          I1=I
          I2=I1-1
          GO TO 30
      ENDIF
   10 CONTINUE
      I1=N
      I2=I1-1
```

```
30   DO 20 J=2,M
     IF(DEV.LT.Y(J)) THEN
          J1=J
          J2=J1-1
          GO TO 40
     ENDIF
20   CONTINUE
     J1=M
     J2=J1-1
40   U1=(X(I1)-DUM)/(X(I1)-X(I2))
     U2=B(J2,I1)-(B(J2,I1)-B(J2,I2))*U1
     U3=B(J1,I1)-(B(J1,I1)-B(J1,I2))*U1
     U4=(Y(J1)-DEV)/(Y(J1)-Y(J2))
     LB=U3-(U3-U2)*U4
     RETURN
     WRITE(6,300)
300  FORMAT('OUT OF SCALE')
     RETURN
     END
```

I.6 Variables of the Second Program

1) iso$: Name of the isotope
2) x1 : Thickness of the specimen in cm
3) x2 : Height of the medium in cm
4) sfd : Source to film distance in cm
5) s : Activity of the source in Curies
6) df : Density factor
7) fd : Film factor in cm^{-2}
8) d : Density in gr/cm^{3}
9) m : Linear absorption coefficient cm^{-1}
10) e1 : A constant
11) e2 : A constant
12) t : Exposure time without medium in min.
13) t1 : Exposure time with medium in min.

I.7 The Computer Program Utilizing the Theoretical Method or All Isotopes Using Water or Oil as a Second Medium

```
10 REM exposure time determination with more than one
   medium
20 PRINT "******* This program determines the exposure
   time with different media *******"
30 PRINT"******* You have a choice to select Co-60,
   Ir-192, Cs-137 or Ra-226      *******"
40 PRINT "******* You can select water or oil
   as the medium only if you use Co-60 *******"
50 INPUT "Enter the thickness of the specimen in cm";x1
60 INPUT "Type the name of the isotope";iso$
70 A$=LEFT$(iso$,2)
80 IF a$="cs"   THEN GOSUB 1000
90 IF a$="co" THEN GOSUB 2000
100 IF a$="ir" THEN GOSUB 3000
110 IF a$="ra" THEN GOSUB 4000
120 PRINT "****** Sorry!!!  The isotope you used is not
    employed in our program.*****"
130 PRINT" If you want to go on with the isotopes
    mentioned print Y otherwise the program will be
    terminated"
140 INPUT B$
150 IF LEFT$(B$,1)="y" THEN GOTO 50 ELSE STOP
160 INPUT "Enter the height of the medium in cm";x2
170 INPUT "Enter source to film distance in cm";sfd
175 INPUT "Enter the activity of the source in curies";s
180 INPUT "Enter the density factor; if you want 2.00
    density enter (1)";df
185 INPUT "Enter the film factor";fd
190 DEF FNT(e1,e2)=e1*EXP(e2*x2)
200 d=7.86
210 t=(fd*sfd↑2)*EXP(m*x1*d)*df/(s*3.7E+10*60)
220 t1=t*FNT(e1,e2)
```

```
230 PRINT USING "t=######.## min (exposure time without
    medium) t1=#######.## min (exposure time with
    medium)";t,t1
235 END
1000 PRINT "******You can only choose water as  the
     medium working with Cs-137******"
1010 e1=1:m=0.042:e2=0.08264
1011 IF x1<2 OR x1>10 THEN PRINT"The specimen is not
     appropriate for this isotope":STOP
1015 GOTO 160
1020 RETURN
2000 PRINT " ****** You may choose water or oil as
     the medium *******"
2010 INPUT"Enter the medium you used";C$
2020 IF LEFT$(C$,1)="w" THEN GOTO 2060
2030 IF LEFT$(C$,1)="0" THEN GOTO 2050
2040 PRINT "Unfortunately, we cannot satisfy your
     needs":STOP
2045 IF x1<4 OR x1>20 THEN PRINT"The specimen is not
     appropriate for this isotope":STOP
2050 m=0.035:e1=16.49/19:e2=0.03687:GOTO 160
2060 m=0.035:e1=16.44/19:e2=0.03905
2065 GOTO 160
2070 RETURN
3000 PRINT"You may only choose water as the medium "
3010 e1=1:m=0.049:e2=0.08877
3011 IF x1<1.2 OR x1>10 THEN PRINT"The specimen is not
     appropriate for this isotope":STOP
3015 GOTO 160
3020 RETURN
4000 PRINT"The calculations are made in case of water
     as the medium"
4010 m1=0.039:e1=1:e2=0.06804
4011 IF x1<5 OR x1>15 THEN PRINT"The specimen is not
     appropriate for this isotope":STOP
```

```
4015 GOTO 160
4020 RETURN
```

APPENDIX II

"THE MEDIUM FACTOR TABLES"

Table II.1

Medium Height (cm)	Medium Factors for Cs-137 (Water)	Ir-192 (Water)
0	1.00	1.00
1	1.09	1.09
2	1.18	1.19
3	1.28	1.31
4	1.39	1.43
5	1.51	1.56
6	1.64	1.70
7	1.78	1.86
8	1.94	2.03
9	2.10	2.22
10	2.29	2.43
11	2.48	2.66
12	2.70	2.90
13	2.93	3.17
14	3.18	3.47
15	3.45	3.79
16	3.75	4.14
17	4.08	4.52
18	4.43	4.94
19	4.81	5.40
20	5.22	5.90
21	5.67	6.45
22	6.16	7.05
23	6.69	7.70
24	7.27	8.42
25	7.89	9.20
26	8.57	10.05
27	9.31	10.99
28	10.11	12.01
29	10.99	13.12

Table II.1 (cont.)

Medium Height (cm)	Medium Factors for Cs-137 (Water)	Ir-192 (Water)
30	11.93	14.34
31	12.96	15.67
32	14.08	17.13
33	15.29	18.72
34	16.61	20.45
35	18.04	22.35
36	19.59	24.43
37	21.28	26.70
38	23.11	29.17
39	25.10	31.88
40	27.26	34.84
41	29.61	38.08
42	32.17	41.61
43	34.94	45.47
44	37.95	49.69
45	41.21	54.31
46	44.77	59.35
47	48.62	64.86
48	52.81	70.88
49	57.36	77.46
50	62.30	84.65

Table II.2

Medium Height (cm)	Medium Factors for Ra-226 (Water)	X-Rays (Water)
0	1.00	1.00
1	1.07	1.21
2	1.15	1.33
3	1.23	1.47
4	1.31	1.63
5	1.41	1.80
6	1.50	1.98
7	1.61	2.19
8	1.72	2.42
9	1.84	2.67
10	1.97	2.95
11	2.11	3.26
12	2.26	3.60
13	2.42	3.98
14	2.59	4.39
15	2.77	4.85
16	2.97	5.36
17	3.18	5.92
18	3.40	6.53
19	3.64	7.22
20	3.90	7.97
21	4.17	8.80
22	4.47	9.72
23	4.78	10.74
24	5.12	11.86
25	5.48	13.10
26	5.87	14.47
27	6.28	15.98
28	6.72	17.66
29	7.19	19.50

Table II.2 (cont.)

Medium Height (cm)	Medium Factors for Ra-226 (Water)	X-Rays (Water)
30	7.70	21.54
31	8.24	23.79
32	8.82	26.27
33	9.44	29.02
34	10.11	32.05
35	10.82	35.40
36	11.58	39.10
37	12.40	43.19
38	13.27	47.70
39	14.20	52.68
40	15.20	58.19
41	16.28	64.27
42	17.42	70.99
43	18.65	78.40
44	19.96	86.60
45	21.37	95.65
46	22.87	105.64
47	24.48	116.68
48	26.20	128.87
49	28.05	142.34
50	30.02	157.21

Table II.3

Medium Height (cm)	Medium Factors for Co-60 (Water)	Co-60 (Oil)
0	1.00	1.00
1	1.00	1.00
2	1.00	1.00
3	1.00	1.00
4	1.01	1.01
5	1.05	1.04
6	1.09	1.08
7	1.14	1.12
8	1.18	1.17
9	1.23	1.21
10	1.28	1.25
11	1.33	1.30
12	1.38	1.35
13	1.44	1.40
14	1.49	1.45
15	1.55	1.51
16	1.62	1.57
17	1.68	1.62
18	1.75	1.69
19	1.82	1.75
20	1.89	1.81
21	1.96	1.88
22	2.04	1.95
23	2.12	2.03
24	2.21	2.10
25	2.30	2.18
26	2.39	2.26
27	2.48	2.35
28	2.58	2.44
29	2.69	2.53

Table II.3 (cont.)

Medium Height (cm)	Medium Factors for Co-60 (Water)	Co-60 (Oil)
30	2.79	2.62
31	2.90	2.72
32	3.02	2.82
33	3.14	2.93
34	3.26	3.04
35	3.39	3.15
36	3.53	3.27
37	3.67	3.40
38	3.82	3.52
39	3.97	3.66
40	4.13	3.79
41	4.29	3.94
42	4.46	4.08
43	4.64	4.24
44	4.82	4.40
45	5.02	4.56
46	5.22	4.73
47	5.42	4.91
48	5.64	5.09
49	5.86	5.29
50	6.10	5.48

APPENDIX III

"THE AUXILIARY PROGRAMS"

This program determines the required exposure time for 2.00 density. In radiography, it is essencially very difficult to get 2.00 density radiographs, since the experimental conditions, the age of the films or other parameters cannot be kept constant. So, it is a common experience that using the experimental results, the required exposure time can be obtained by interpolation.

Using this program, three inputs should be entered.

1) Experimental condition; a code to remember,
2) The density that was obtained experimentally,
3) The previous exposure time.

```
10 DIM p(6),l(6)
20 FOR i=1 TO 6:READ p(i),l(i):NEXT i
30 DATA .5,.16,1.0,.43,1.5,.71,2.0,1.0,2.5,1.30,3.0,1.63
40 INPUT "enter the experimental condition ";at$
50 INPUT "enter the experimentally found density";p
55 INPUT" enter the exposure time";tt
60 IF p<p(1) OR p>p(6) THEN PRINT "out of scale":STOP
70 x1=p(1)
80 FOR j=2 TO 6
90 IF p<p(j) THEN x2=p(J):x1=p(j-1):y2=l(j):y1=l(j-1):GOTO
   110
100 NEXT j
110 q=y1+(p-x1)/(x2-x1)*(y2-y1)
120 TGER=tt/q
140 PRINT USING "EXP. CONDITION=&&&&&&& ";at$
150 PRINT USING "DENSITY=##.## FDSFA=###.###
    TGER=###.##";p,q,tger
162 LPRINT USING "EXP. CONDITION=&&&&&&& ";at$
163 LPRINT USING "DENSITY=##.## FDSFA=###.### TGER=###.##
    min";p,q,tger
170 GOTO 40
180 END
```

This is the program employed in preparation of the medium factor tables. During the execution of the program, a file is opened and the necessary information is written there. The results are also printed on the screen. If a different table with different increments is desired, the iteration loop can be changed accordingly.

```
10 DEF FNA1(x)=EXP(0.08264*x)
20 DEF FNA2(x)=EXP(0.08877*x)
30 DEF FNA3(x)=EXP(0.06804*x)
40 DEF FNCW(x)=16.44/19*EXP(0.03905*x)
50 DEF FNCO(X)=16.49/19*EXP(0.03687*x)
60 DEF FNXW(x)=4.008/3.67*EXP(0.09939*x)
65 OPEN "o",1 ,"b1.bas"
70 FOR x=1 TO 50
80 a1=FNa1(x)
90 a2=FNa2(x)
100 a3=FNa3(x)
110 a4=FNcw(x)
120 a5=FNco(x)
130 a6=FNxw(x)
140 PRINT x,a1,a2,a3,a4,a5,a5
141 PRINT #1 USING"## ##.## ##.## ##.## ##.## ##.##
    ###.##";x,a1,a2,a3,a4,a5,a6
150 NEXT
160 CLOSE
170 END
```

APPENDIX IV

"THE TABLES UTILIZED"

Table IV-1 Film factors for film types, film densities and most common radioactive sources

Radiographic 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
C0-60	Eastman AA-Structurix D7	8.6	16.0	48.0
Co-60	Eastman KK-Structurix D4	52.0	70.0	116.0
Cs-137	Eastman KK-Structurix D10	8.1	13.0	31.0
Cs-137	Eastman KK-Structurix D7	24.0	44.0	138.0
Cs-137	Eastman KK-Structurix D4	148.0	200.0	330.0
Ir-192	Eastman KK-Structurix D10	7.6	12.0	30.0
Ir-192	Eastman KK-Structurix D7	23.0	42.0	130.0
Ir-192	Eastman KK-Structurix D4	140.0	190.0	315.0

Table IV-2 Dose built-up factors for a point isotropic source, (Material : Steel)

Mev	ψ*x 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	13.5
10.0	1.20	1.42	1.95	2.99	4.35	7.54	12.4

Table IV-3 Relative speeds of various films

Kodak Film	Relative speed	Agfa Geavart Film
-	0.5	Structurix D2 (single coat)
-	1	Structurix D2
Industrex M	4	Structurix D4
-	8	Structurix D5
Industrex A	16	Structurix D7
Industrex C		Structurix D7
Industrex D	32	-
Kodirex	64	Structurix D10

REFERENCES

1) Bilge, A., N., Nucleer Tekniklerin Endustriye Uygulanmasi, TAEK Bilimsel Yayin No: 1 1985.

2) Gardner, R., P., Ely, R., L., Radioisotope Measurement Applications in Engineering, Reinhold Publishing Corp. 1967.

3) Mustafa, N., Ghauri, G., A., Ahmad, M., and Khan, A., A. Notes on Industrial Radiography, Pakistan Institude of Nuclear Science and Technology, Islamabad, April 1975.

4) Elchholz, G., Radioisotope Engineering, Marcel Dekker Inc. New York 1972.

5) Piraux, H., Radioisotopes and their Industrial Applications, Philips Technical Library, 1964.

6) Buyukyuksel, Sinan, "Evalution of Gammagraphy for Different Materials", M. S. Thesis in B.U. 1984.

7) Bilge, A., N., Tugrul, B., Sanayide Uygulamali Radyografi, "Segem" Haziran 1986.

8) Mc Gonnagle, W., J., Nondestructive Testing, Gordon and Breach New York 1971.

9) Libby, H., Introduction to Electromagnetic Test Methods, New York, Wiley-Interscience, 1971.

10) Agfa-Geavart, Radiofilms Industries, Anvers, 1980

11) Faires, R., A., Barks, B., H., Radioisotope Laboratory Techniques, London Bulturworths, 1973.

12) Krane, K., S., Modern Physics, John Wiley & Sons, Inc. 1983