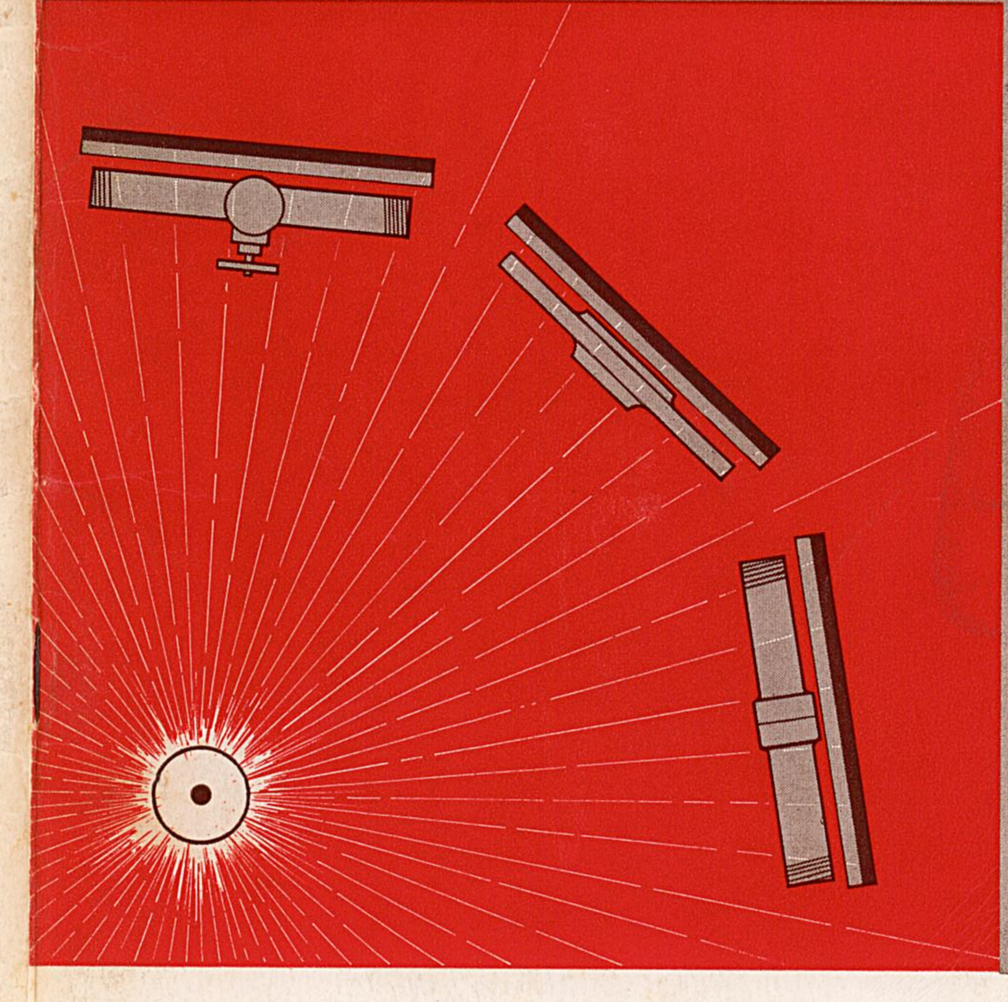
# INDUSTRIAL RADIOGRAPHY

## WITH RADIOISOTOPES

N.W.D. Chrimes



AUSTRALIAN ATOMIC ENERGY COMMISSION

# INDUSTRIAL RADIOGRAPHY

## WITH RADIOISOTOPES

N. W. D. Chrimes, B.Sc. (Birm.), M.Weld.I., A.I.M.

Materials Division,
Australian Atomic Energy Commission Research Establishment,
Lucas Heights, Sydney

AUSTRALIAN ATOMIC ENERGY COMMISSION
1970

# Preface

Radiography is one of the principal non-destructive test methods used in industry. Its use is increasing as modern technology demands greater product reliability.

Radioisotope sources enable the manufacture of relatively cheap, portable and sturdy equipment for industrial radiography. These machines are simple to operate and maintain, they provide economic radiographic facilities which have advantages for small industrial organisations and for operators in remote areas.

If the best results are to be obtained from radiography, the work must be done by conscientious operators using suitable equipment, with techniques based on the principles of radiological physics.

The purpose of this handbook is to describe good radiographic technique and discuss its principles. The five sections deal with General Principles of Radiography, Properties and Production of Radioisotopes, Radiographic Technique, Interpretation of Radiographs, and Radiation Protection. The last mentioned section refers to the various State and Commonwealth Regulations which are listed in the bibliography.

# Contents

## SECTION 1.

## SECTION 2.

## SECTION 3.

## SECTION 4.

## SECTION 5.

## APPENDIX

## GLOSSARY

## LIST OF TABLES

## LIST OF FIGURES

**Figure No.**

**Figure No.**

## LIST OF PLATES

**Plate No.**

## ACKNOWLEDGMENTS

The author wishes to express his appreciation to Mr. P. A. Gillespie for helpful comments and to members of the Non-Destructive Testing Association of Australia for assistance in supplying radiographs and specimens.

## Section 1

# GENERAL PRINCIPLES OF RADIOGRAPHY

## PRODUCTION OF IMAGES

The basic radiographic process is the detection of density differences in materials by the preferential absorption of X-rays. Normally, these differences are recorded as variations in the blackening of a photographic film. When the image of the material is recorded on film, the blackest areas correspond to parts of the material with low density (which absorb less radiation than those of high density). Also, for a given thickness, the larger is the diameter of the flaw the greater the variation in density in adjacent areas of the film.

## SENSITIVITY

Radiographic sensitivity is the ability of the method to detect flaws represented by variations in density of adjacent areas of film. In industrial radiography, by using suitable techniques it should be possible to reveal defects equivalent to 2% of the total section thickness. The factors affecting sensitivity are discussed below.

### Contrast

In film radiography, contrast is the difference in film density between the image of the defect and that of the surrounding area. When a beam of radiation passes through an absorber the relation between the emergent and initial intensities I and $I_O$ is expressed by Lambert's Law:

$$\frac{I}{I_O} = e^{-\mu t} \qquad \ldots (1)$$

where t is the specimen thickness and μ the linear absorption coefficient.

If the absorber contains a defect of thickness Δt (Figure 1) with an absorption coefficient $\mu_D$ the ratio of the emergent intensities of beams passing through the "sound" material $I_1$ and through the defect $I_2$ is given by the equation

$$\frac{I_1}{I_2} = e^{-\Delta t(\mu - \mu_D)} \qquad \ldots (2)$$

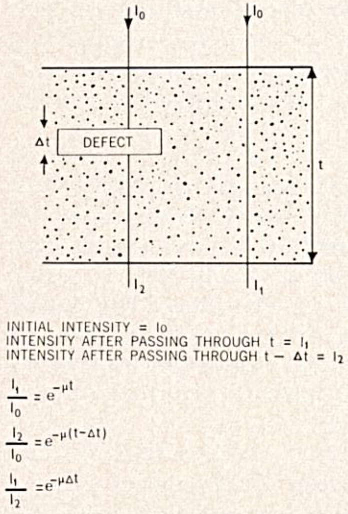
To distinguish a defect, the value of $I_1/I_2$ should be as small as possible. To ensure this, both μ and $\mu - \mu_D$ should be high. For a given absorber material, μ shows a general increase with decreasing radiation energy and therefore contrast increases also.

Unfortunately, high values of μ mean heavier overall absorption, requiring longer exposure times because the film must receive a minimum amount of radiation to produce a radiograph of satisfactory density. The rule for achieving optimum contrast therefore is to use minimum radiation energy consistent with exposure time.

### Definition

Definition is sharpness of image outline. Production of a radiograph involves projection of an image of a defect onto a film, fluoroscopic screen or other recording medium. Ideal sharpness can be obtained only from a point radiation source or from a source of finite size at an infinite distance. In practice, it is necessary to compromise by using a source of the smallest practicable diameter at the greatest convenient distance commensurate with a reasonable exposure time (See Figure 2). In the formula given for unsharpness ($Ug = \frac{l}{L - l} \times D$), the source diameter D for gamma radiography is normally 1, 2 or 4 mm and the source-to-film distance L is proportional to the defect-to-film distance l and hence to the section thickness for the same amounts of unsharpness. Selection of suitable values for D and L must be based on the following considerations:

(a) The maximum permissible value of the geometric unsharpness Ug — this is normally specified in the code of practice or specification, but a value of 0.2 mm is typical.



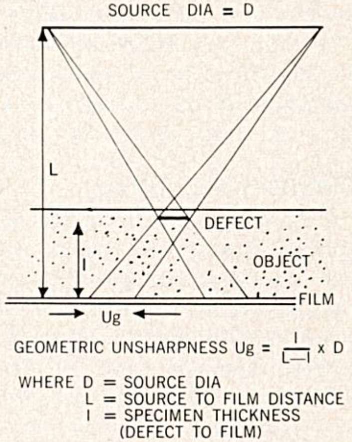


*Figure 1. Left: Effect of defect size and absorption coefficient on contrast.*
*Figure 2. Above: Calculation of geometric unsharpness.*

(b) The maximum practicable exposure time — this is usually in the range 1 to 10 hours. It is influenced by

- (i) *The source to film distance L* — Exposure time is directly proportional to $L^2$ under equivalent conditions.
- (ii) *Source size* — Gamma-ray sources for radiography normally are supplied as right cylinders (i.e. their height equals their diameter). As activity is proportional to the cube of this dimension, exposure time is inversely proportional to the source diameter for equivalent exposure conditions.

### Scattering

Reduction in intensity of the primary beam, as it passes through an absorber, is caused by processes which involve both absorption and scatter of radiation. Scatter, which takes place in all directions, occurs at all points in the specimen producing a general veil of radiation which lowers image contrast. A significant proportion of the scattered radiation is of lower energy than that of the primary beam. In general, the amount of scatter depends on the nature and thickness of the absorber material and on the energy of the primary beam. Thick specimens and low radiation energies result in a high proportion of scatter. Of the total radiation reaching the film, only that in the primary beam will carry a coherent image, and this is only a small part of the total.

## IMAGE AND FILM FACTORS

For optimum sensitivity, the image should be produced by radiation at the lowest energy level consistent with exposure time. The geometry of the arrangement also is important and the type of film used has a pronounced effect on both the contrast and definition of the radiograph. Films available for radiography vary both in speed and grain and are discussed on page 29.

### Sensitometric Curves

The opacity of a film exposed to gamma-rays which have passed through an object is in proportion to the intensity of the emergent beam, which is in proportion to the transparency of the object to radiation. The logarithm of the opacity of an area of the film is called the density of the film. Thus a film which transmits 1/10 of the viewing illumination has a density of 1.0, and for 1/100, 1/1,000 or 1/10,000 of the light transmitted the respective densities are 2.0, 3.0 and 4.0. In practice, the optimum density range is between 2.0 and 3.0 but films with densities of up to 4.0 may be examined on a high-intensity viewer.

Under standard processing conditions the density of a given type of film depends on the intensity of the radiation falling on it and on exposure time. These factors can be regarded as interdependent and the exposure of a film will, in fact, be the product of the time and intensity.

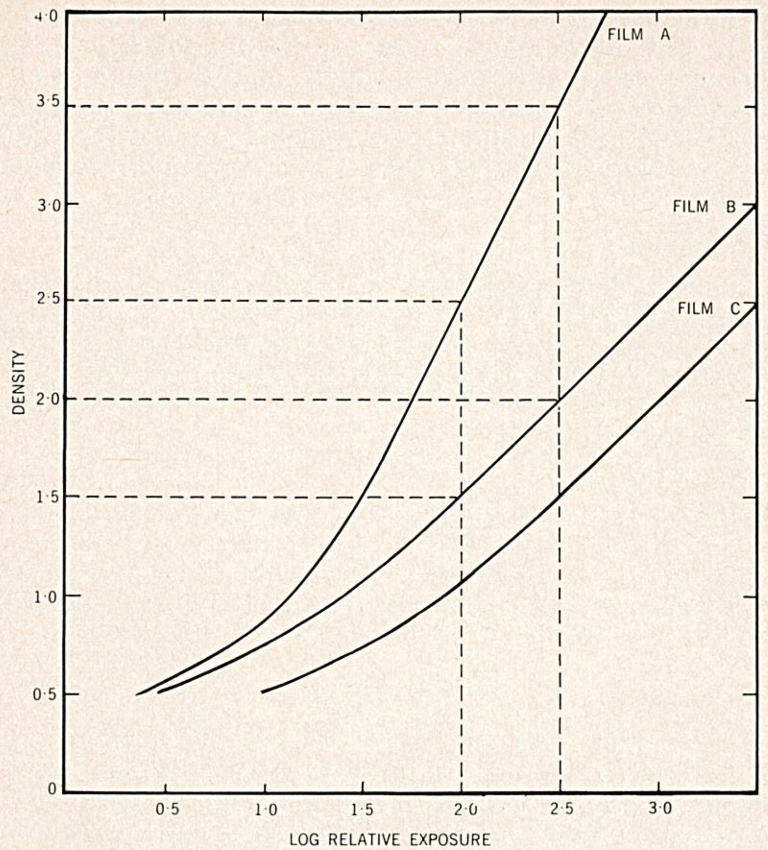


*Figure 3. Typical sensitometric curves.*

Relation between film density and exposure can be found by exposing a number of film strips for a range of time intervals. The densities of the processed films are determined on a densitometer and plotted against the logarithm (to base ten) of the exposure to produce a characteristic or "sensitometric" curve. The abscissae should be plotted on a logarithmic scale giving a practical form of graph. Curves for three hypothetical films are shown in Figure 3. In each case the curve has two parts; at first the slope increases with exposure but then remains constant up to a density of about 4.0

### Film Contrast

The gradient of the sensitometric curve indicates film contrast. As the gradient increases, density difference for a given increase in exposure will increase. Thus, with films A and B (Figure 3), increasing the logarithm of the relative exposure from 2.0 to 2.5 produces a density difference of 1.0 in film A and 0.5 in film B. Film contrast of A is therefore 1.0/0.5 = 2 and for B 0.5/0.5 = 1. If the slope is taken from non-rectilinear portions of the curve, lower values for film contrast will be obtained, but in normal practice this portion is not used. The term "gamma" is given to the gradient of the rectilinear portion of the curve.

### Film Speed

In addition to variations in gradient, films may differ in the exposure required to produce a given density. This difference in film "speed" may or may not be accompanied by differences in gradient. Thus, in Figure 3, film A is faster than film B and also has a greater gamma, and film B is faster than film C, though having the same gamma.

### Film Unsharpness

Just as contrast is determined by the type of film and by selection of the energy of the radiation source, so definition is controlled by film type and image factors. Even a linear boundary radiographed by a point-radiation source will have some unsharpness due to scattering of photons in the film emulsion.

## FILM PROCESSING

The latent image formed by the action of gamma-rays on silver halide grains is made visible by treating the film with a developing solution and then removing unaffected silver halide grains in a "fixing" operation. Finally, all traces of chemical processing solutions must be washed from the film with water.

Details of processing procedures are supplied by a number of film manufacturers (See Appendix) but the following points are considered important

(a) The standard development time is normally 5 minutes at 68°F. For higher or lower temperatures the time is respectively decreased or increased. It is necessary to agitate the film in the developer every 30 seconds.

(b) The action of the developer is halted in a "stop" bath consisting of 1.5% acetic acid in water.

(c) The film is fixed, preferably in two stages using one fixing solution to clear the film and then transferring it into a second fixing solution for the same time. When the clearing time for the first solution exceeds 4 minutes it is discarded and replaced by partly used fixer from the second bath which is in turn replaced by a fresh solution.

(d) Films should be washed in running water for at least 30 minutes before drying.

Small to moderate deviations in the correct exposure can be compensated for by varying the development time. Thus under-exposure can be rectified to some extent, and the film's density and contrast improved, by increasing the development time. However, excessive development will lead to fogging and the reduced density of an underdeveloped film will be accompanied by lack of contrast.

## USE OF LEAD INTENSIFYING SCREENS

Lead intensifying screens used for gamma radiography have two purposes — they absorb scattered radiation and, owing to their emission of beta and secondary X-radiation, produce an intensifying effect which may reduce the exposure by a factor of up to three.

Recommended screen thicknesses in inches for the commonly used radioisotopes are:

| | *Front Screen* (in.) | *Back Screen* (in.) |
|---|---|---|
| Thulium 170 | 0.0015 | 0.004 |
| Iridium 192 | 0.004 | 0.004 |
| Caesium 137 | 0.005 | 0.005 |
| Cobalt 60 | 0.006 | 0.006 |

## OTHER IMAGE RECORDING DEVICES

### Fluoroscopy

The use of fluorescent screens coated with barium platinocyanide and similar materials as an image recording device is attractive from the cost point of view. Although convenient, they give sensitivities substantially inferior to those obtained with films. X-rays generated at potentials of up to 150kV are normally used for fluoroscopy. Gamma-rays from radioisotopes can be used with fluoroscopic screens but their comparatively low intensities result in low image brightness and their high radiation energy makes shielding of the operator difficult.

### Xeroradiography

Another image recording device is the xerographic plate. After charging, a selenium covered metal plate is "exposed" in a light-tight box and subsequently "developed" by dusting with charged particles which adhere to the plate and form an image in proportion to the remaining charge.

Sensitivities obtained by this technique are much better than for fluoroscopy and are comparable to those obtained in film radiography. However, it is difficult to produce suitable plates for the relatively high energy gamma-rays from radioisotope sources, and little work has been done in this field.

## EXPOSURE TECHNIQUE

### Effect of Varying Gamma-Ray Photon Energy and Intensity

Clearly the selection of a radiation source with optimum gamma-ray photon energy and intensity is important. The following table summarises the effect that increasing photon energy and intensity has on contrast and definition.

| *Factor* | *Effect of increased photon energy* | *Effect of increased photon intensity* |
|---|---|---|
| CONTRAST | | |
| Image contrast | Decrease | Not affected |
| Film contrast | Not affected | Not affected |
| Scatter | Increase | Not affected |
| DEFINITION | | |
| Geometric unsharpness | Not affected | Increase* |
| Film unsharpness | Decrease | Not affected |
| Scatter unsharpness | Increase | Not affected |

* Permits longer source/film distances.

## Section 2

# PROPERTIES AND PRODUCTION OF RADIOISOTOPES USED FOR RADIOGRAPHY

## CRITERIA FOR USE OF ARTIFICIAL RADIOISOTOPES

The great expansion in the use of radioactive materials for industrial radiography is due to their availability from nuclear reactors, either as materials activated by neutron bombardment or as fission products.

Although many artificial radioisotopes can be used for radiography, there are certain criteria to be applied in the selection of a radioisotope source. These are as follows.

### Appropriate Gamma-Ray Photon Energy

A radioactive material may emit corpuscular ($\alpha$ and $\beta$) as well as electromagnetic ($\gamma$) radiation. In general, only gamma radiation is of interest to the radiographer and its energy must suit the nature and thickness of material being examined. Gamma-ray photon energy is usually expressed in "electron volts" and commonly used units are 1 MeV (1 million electron volts) and 1 keV (1 thousand electron volts). The energy of gamma radiation is related to its wavelength, that is, the shorter the wavelength the greater is the energy or penetrating power.

### Long Half-Life

For economy, it is desirable to use radioisotopes which do not have a rapid decay rate. Rate of decay is conveniently indicated by the "half-life", the time taken for half the radioactive atoms to decay, and a long half-life is preferred.

### High Specific Activity

To keep exposure times short it is necessary to have an adequate quantity of radiation (of a given energy). The quantity of radiation is proportional to the number of radioactive atoms present and is expressed in roentgens (see page 47). The activity of a radioactive source is usually expressed in curies (1 Ci = 3.7 x $10^{10}$ disintegrations per sec.).

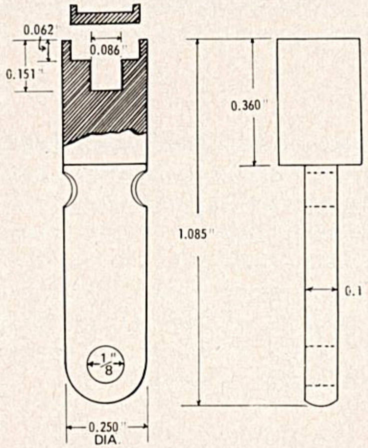
For optimum definition the source must have a high activity and be concentrated into a minimum volume. Its "specific activity" is expressed as activity per unit mass (usually curies per gram).

Where the radioactive source is produced by neutron bombardment, the upper limit for specific activity is set by available neutron density per unit surface area of the source and the decay characteristics of the particular radioisotope.

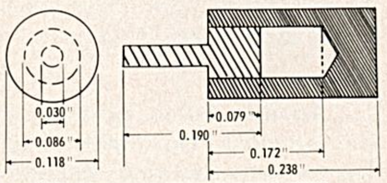
Where the source is produced by uranium fission, the abundance of the fission product and the compound in which it is contained are the only factors that determine the activity of the source.

### Suitable Target Materials

The ideal target material is a readily available chemically inert solid which, after irradiation by neutrons in a nuclear reactor, produces a gamma emitter in adequate quantity with satisfactory radiation energy and fairly long half-life.



TYPE 'A' CAPSULE WITH HANDLING TAG
SUITABLE FOR IRIDIUM 192 AND COBALT 60 SOURCES 2 x 2 mm
(Also available for 1 x 1 mm, 3 x 3 mm and 4 x 4 mm sources)



TYPE 'C' CAPSULE FOR FLEXIDRIVE TYPE CAMERAS
SUITABLE FOR IRIDIUM 192 AND COBALT 60 SOURCES 2 x 2 mm
(Also available for 1 x 1 mm sources)

*Figure 4. Standard radiography capsules.*

On the above criteria, the few most suitable radioisotopes for industrial radiography are cobalt 60, iridium 192 and thulium 170, which are produced by neutron irradiation, and caesium 137 which is a fission product extracted from spent nuclear fuel. Their main characteristics are given in Table 1. Typical sources are shown in Figure 4.

Table 2 shows the typical size, activity, and radiation output of sources. Decay charts are available which enable calculation of the residual activity of sources after use for some time.

## RADIOISOTOPE SOURCES IN COMMON USE IN INDUSTRIAL RADIOGRAPHY

### Cobalt 60

Of the high energy radioisotopes (> 1 MeV) cobalt 60 is the most popular because of its long half-life (5.3 years), relatively high specific activity and low cost of target material. Its main gamma energies are 1.17 and 1.33 MeV so its radiation is essentially monochromatic (see page 47). Its quality is not affected appreciably by filtering. In general cobalt 60 is used for sections equivalent to $1\frac{1}{2}$ to 6 in. of steel but its sensitivity for sections of less than 2 in. is not acceptable (Reference 1).

### Caesium 137

Caesium 137 radiation is monochromatic and its energy (0.66 MeV) in intermediate between the average values for cobalt 60 and iridium 192. Unlike the radioisotopes commonly used for radiography, caesium 137 is a fission product. It has low specific activity but is used by many operators because of its long half-life (30 years). It requires practically no adjustment of exposure to allow for decay. Though less frequently used than caesium 137, caesium 134 (half-life of 2.3 years and average energy similar to that of caesium 137) can be used for similar thickness (equivalent to 1 in. to 4 in. of steel). Some regulations (Reference 2) prescribe a wipe test at six-monthly intervals to check possible contamination arising from leakage.

### Iridium 192

Iridium 192 is probably the most widely used radioisotope for industrial radiography. Its gamma-ray spectrum is complex and has components with energies ranging from approximately 0.3 to 1.2 MeV, with the largest emission abundances ranging from 0.3 to 0.47 MeV. The recommended thickness range is for sections equivalent to $\frac{1}{2}$ in. to 3 in. of steel. Iridium 192 with very high specific activity can be produced (Table 1) and this allows short exposures and better image definition. Its short half-life of 74 days is a major disadvantage, however.

### Thulium 170

Thulium 170 is used mainly for the radiography of aluminium alloys in the thickness range $\frac{1}{2}$ in. to 2 in. The energy of its

## TABLE 1

## CHARACTERISTICS OF PRINCIPAL RADIOISOTOPES USED FOR RADIOGRAPHY

| Isotope | Radiation Energy (MeV) | Half-Life | Maximum Practical Specific Activity (curies/g) | Dose Rate* (r.h.m.† /curie) | Optimum Material Thickness Range (in.) |
|---|---|---|---|---|---|
| Cobalt 60 | 1.17, 1.33 | 5.3 a | 50 | 1.35 | Steel<br>$1\frac{1}{2}$-6 |
| Caesium 137 | 0.66 | 30 a | 25 | 0.37 | Steel<br>1-4 |
| Iridium 192 | 0.3-1.2 | 74 d | 500 | 0.55 | Steel<br>$\frac{1}{2}$-3 |
| Thulium 170 | 0.084 | 127 d | 50 | 0.0025 | Aluminium<br>$\frac{1}{2}$-2 |

* Dose rate in roentgens/h at a distance of 1 metre from the source. Dose rates at other distances can be calculated on the basis of the inverse square law.

## TABLE 2

## TYPICAL SOURCE SIZES, CURIE RATINGS AND RADIATION OUTPUT OF COMMONLY USED RADIOISOTOPE RADIATION SOURCES

| Isotope | Source Dimensions (mm) | Maximum Activity (Ci) | Radiation Output (r.h.m.)† |
|---|---|---|---|
| Cobalt 60 | 1 x 1 | 1.0 | 1.35 |
| | 2 x 2 | 2.5 | 3.38 |
| | 3 x 3 | 5.0 | 6.76 |
| | 4 x 4 | 20.0 | 27.0 |
| Caesium 137 | 3 x 3 | 1.75 | 0.6 |
| Iridium 192 | 0.5 x 0.5 | 1.0 | 0.55 |
| | 1 x 1 | 6.0 | 3.3 |
| | 2 x 2 | 30.0 | 16.5 |
| | 3 x 3 | 50.0 | 27.5 |
| | 4 x 4 | 100.0 | 55.0 |
| Thulium 170 | 4 x 4 | 50.0 | 0.12 |

† r.h.m. = roentgens/h at a distance of 1 metre

principal gamma emission is 0.084 MeV and its half-life 127 days. Its comparatively low specific activity and resultant low dose rate necessitates long exposures in reactors such as HIFAR.

### Other Radioisotope Sources Proposed For Radiography

Tantalum 182 has similar gamma energies to cobalt 60 but is rarely used because of its much shorter half-life (112 days) and appreciably lower specific activity.

Caesium 134, already referred to as a substitute for caesium 137, covers about the same range as iridium 192.

In the low energy range samarium 145, samarium 153 and gadolinium 153 have been proposed as suitable for light alloys (Reference 3), but their specific activities are inadequate, and target materials too costly.

## PRODUCTION AND ENCAPSULATION OF RADIOISOTOPES

### Source Encapsulation

Radiography sources are usually supplied in two distinct shapes (Figure 4). One shape is designed to fit into the source holder of a "teleflex" type remote moving system, the other is based on simpler handling equipment requiring a handling lug. Standardisation of source capsule sizes has been proposed by the International Standards Organisation, Technical Committee 85.

In Australia, radiography sources are neutron activated in a primary encapsulation, usually of titanium, and bearing an identification mark and a warning inscription wherever the capsule size permits. Owing to their limited penetration power, sources made from thulium 170 and other low energy gamma emitters are encapsulated in aluminium.

The capsules are sealed by welding and are leak tested by wipe and immersion tests as described in BS 3513: 1962. Particular care is taken in the preparation of the sources to ensure freedom from corrosive elements.

### Irradiation of Target Material in a Nuclear Reactor

Neutron irradiation converts the target material into a radioisotope by the $(n,\gamma)$ reaction:

$$M^A + n^1 = M^{A+1} + \gamma$$

where $M$ represents the target element
$A$ its mass number
$n$ = neutron
$\gamma$ = gamma radiation.

Main factors influencing the number of atoms of target material converted are the neutron flux intensity, possible nuclear reactions that the target material can undergo, and irradiation time. Radioisotope half-life is very important also because net rate of production of radioactive atoms is reduced if the decay rate is high.

The specific activity of a radioisotope $S_r$ in curies/gram is given by the equation:

$$S_r = 0.6\ \Phi\sigma(1 - e^{-0.693t/T})\ /\ W(3.7 \times 10^{10}),$$

where $\Phi$ = neutron flux in neutrons $cm^{-2}\ sec^{-1}$,
$\sigma$ = activation cross section of target in $cm^2$,
$W$ = atomic weight of target material,
$t$ = total irradiation time,
and $T$ = half-life of radioisotope.

Appreciable differences between actual specific activities and those calculated from the formula are due to the following factors:

(a) Reduction in neutron flux as it passes through the target material. Relatively fewer atoms are converted at the centre of the source than near the periphery.
(b) Reduction in neutron flux owing to presence of impurities in the target material if these are good neutron absorbers.
(c) Variations in reactor power which affect the neutron flux.
(d) Reduction of the conversion rate, that is, burn-up of target material, as irradiation proceeds and target atoms are converted to the radioisotope.

## RADIOISOTOPE RADIOGRAPHY EQUIPMENT

Most State Government regulations dealing with the transport and storage of radioactive materials (e.g. N.S.W. Radioactive Substances Act, Reference 4) specify a maximum dose rate of gamma-rays on the surface of the container of 200 milliroentgen/hour and a dose rate of 10 milliroentgen/hour at a distance of 1 metre from the surface.

Attention is drawn to the recommendations of the *Code of Practice for the Control and Safe Handling of Sealed Radioactive Sources used in Industrial Radiography* issued by the National Health and Medical Research Council which are advisory in nature and intended to supplement the various State regulations.

These stipulate dose rates of

(a) 100 milliroentgen per hour at 5 centimetres from the surface of the container.
(b) 10 milliroentgen per hour at 1 metre from the centre of the container.

The *Regulations for the Safe Transport of Radioactive Material* issued by the International Atomic Energy Agency, Vienna 1967, (q.v.) prescribes maximum dose rates of 200 milliroentgen/hour at any point on the external surface and 10 milliroentgen/hour at a distance of 1 metre from the centre. Dose rates are kept within these limits by making containers of shielding materials such as lead or uranium.

An exposure is made by using a shutter mechanism or by moving the source from its container through a tube at the end of a flexible steel cable (Reference 5). Typical exposure containers for radioisotope sources are shown in Plates 1-4.

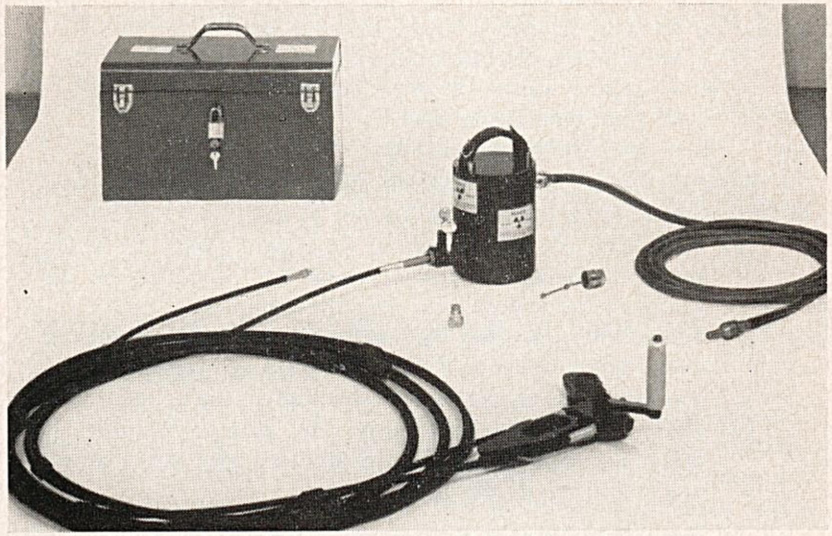


*Plate 1. Exposure Container (Isotope Camera), Philips Dufar, supplied by Philips Electrical Pty. Ltd.*

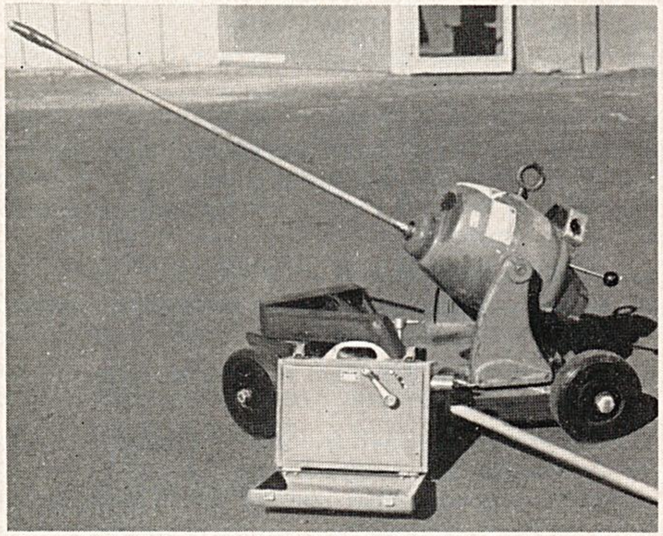
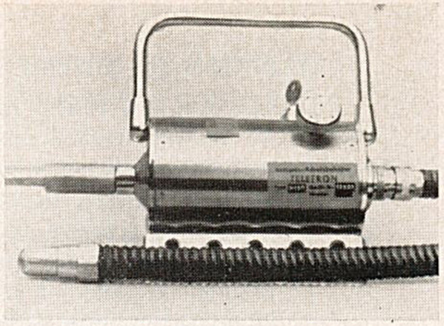


*Plate 2. Exposure Container (Isotope Camera), Pantatron R30, supplied by Amalgamated Wireless (Australasia) Ltd. Trolley by AAEC.*

*Plate 3. Right: Exposure Container (Isotope Camera), Teletron SU50, supplied by Watson Victor Ltd.*



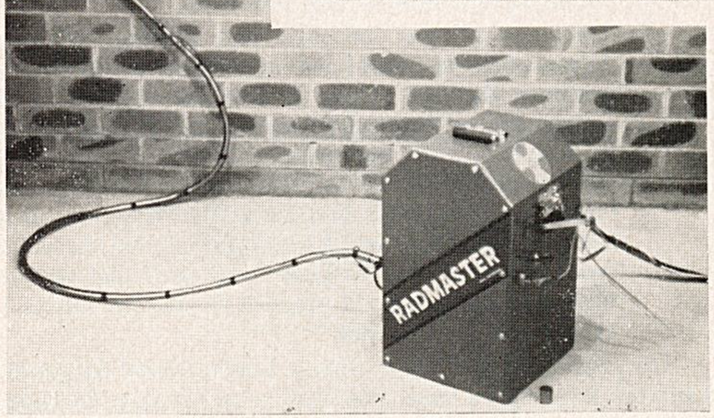


*Plate 4. Exposure Container (Isotope Camera), Radmaster, supplied by Ray-Guard Handling Equipment Co.*

Section 3

# PRACTICAL RADIOGRAPHY TECHNIQUE

## CHOICE OF SUITABLE RADIOISOTOPE

In selecting a radioisotope source for radiography a compromise must be made between increase in penetrating power and decrease in contrast which results from an increase in gamma-ray energy. Maximum contrast is obtained with emitters of low energy radiation but exposure times are too long. Therefore, it is necessary to select a source which gives sufficient sensitivity to reveal harmful defects with the shortest practicable exposure.

The appropriate radioisotopes for the various thickness ranges of steel are discussed on pages 16 and 18 and Table 1. It has been mentioned that sources with a high specific activity are needed if exposure times are to be kept short.

Frequently radiographic work has to be carried out to a particular code or specification which prescribes both sensitivity required and details the technique to be employed.

## SELECTION OF SOURCE/OBJECT/FILM DISTANCE

On page 9 it was shown that improved image sharpness is achieved by having small source diameter and/or long source to specimen distance. However, other factors have some influence:

(a) Distance between the specimen and the film must be as small as possible. For curved surfaces such as tubes, flexible cassettes are available. However, in the case of irregular sections, it may not be possible to achieve minimum specimen to film distances.

(b) Thickness of the specimen and position of possible defects must be considered in relation to the source to specimen distance. Thus, if it is necessary to preserve a given degree of unsharpness, and the specimen thickness is doubled, it is necessary to make a corresponding increase in the source to film distance, it being assumed that a possible defect may be at the maximum distance from the film. However, if it is suspected that characteristic types of defect will be close to a particular surface of the specimen, it is good practice to position this as close as possible to the film.

On page 12 it was shown that a factor related to the ability of films to reproduce a linear boundary must be taken into account. If this "film unsharpness factor" is designated $U_f$ the total unsharpness $U_t$ due to film and geometrical factors is given by the equation:

$$U_t = \sqrt[3]{U_f^3 + U_g^3}$$

where $U_g$ is the geometrical unsharpness.

In practice, $U_g$ should never be greater than $U_f$ (typical values of $U_f$ vary from 0.05 mm for a fine grained, slow film to 0.3 mm for a coarser grained, fast film). However, it can be demonstrated from the above formula that there is little to be gained by making $U_g$ *very small* compared with $U_f$ and that $U_t$ is affected to a decreasing extent as $U_g$ decreases.

An example of the specified focus to film distance, taken from BS2600: 1962, is given in Figure 5.

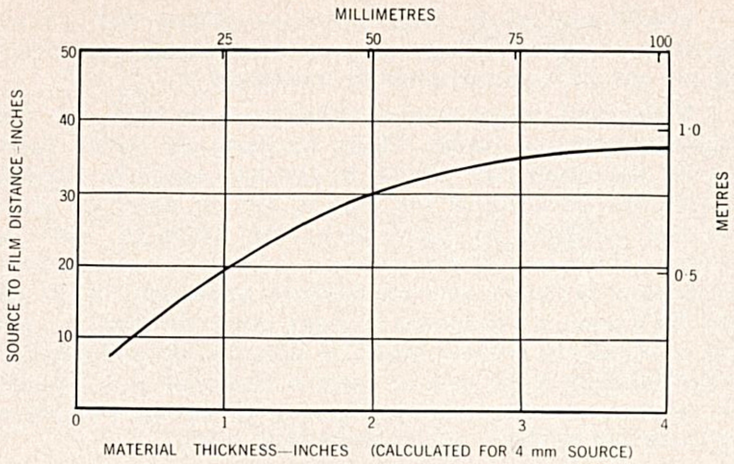
## SELECTION OF EXPOSURES TO OBTAIN OPTIMUM SUBJECT COVERAGE

To minimise distortion, all components in an exposure (source, object, screens and film) should be arranged so that the beam is normal to the surface of the object and the film.

### Radiography of Weldments

(a) *Butt welds*

The usual practice with butt welds is to use a beam directed at right angles to the surface of the weld. In the case of thick sections (> ¼ in.), where the parent material has been specially prepared by chamfering, it may be necessary to align the beam with the plane of the suspected defects, such as lack of side fusion.

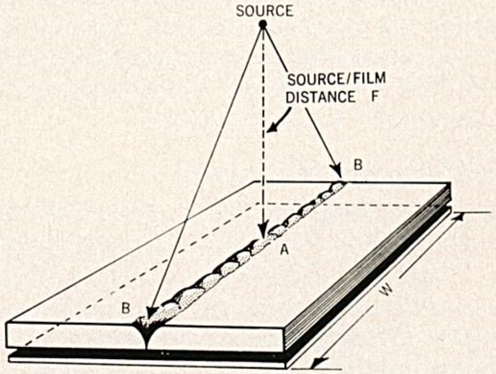


NOTE: FOR A SOURCE OF DIAMETER d (mm) (OTHER THAN 4 mm) THE SOURCE-TO-FILM DISTANCE $F_2$ SHOULD BE EQUAL TO OR GREATER THAN THE VALUE CALCULATED FROM THE FOLLOWING FORMULA:

$F_2 = dF_1/4$

WHERE $F_1$ IS THE SOURCE-TO-FILM DISTANCE FOR A 4 mm DIAMETER SOURCE

*Figure 5.*
*Minimum values of source-to-film distance.*



N.B. Width of film W should be chosen so that incident beam at position B does not traverse specimen thickness greater than 10% of position A.

*Figure 6.*
*Exposure technique for butt welds.*

The length of weld to be penetrated in a single exposure (Figure 6) should be such that the maximum thickness traversed by the beam, at the edge of the film, does not exceed the thickness traversed at the centre of the film by more than 10% (BS2600: 1962, see Appendix).

The method used for circumferential butt welds in a pipe or vessel depends on the diameter and accessibility of the interior.

Double wall double image techniques (Figure 7a) are suitable for tubes or pipes of up to 3½ in. diameter.

Double wall single image techniques (Figure 7b) are used for tubes or pipes of larger diameter where image definition of the top part of the tube would be inadequate.

Single wall single image techniques are used for large diameter pipes and vessels. Figure 7c shows the source outside and the film inside the cylinder. In this case maximum thickness of tube wall traversed at the edge of the film must not exceed the wall thickness by more than 10% (BS2910: 1962, see Appendix). Position of the source in adjacent exposures should be arranged to obtain complete coverage of all parts of the tube wall. In Figure 7d the source is shown inside the pipe or vessel. The source to film distance should be adequate for good definition. If the diameter of the pipe or vessel is such that good definition can be achieved with the source in a central position, a panoramic exposure can be made of the entire weld seam.

In all these techniques it may be necessary to use more than one piece of film, either to provide multiple shots or because the size of available film is insufficient to cover the area under examination.

(b) *Fillet welds*

Fillet welds may be radiographed by directing the beam to bisect the angle of the joint (Figure 8). However, radiography is not considered the best method for non-destructive examination of fillet welds, owing to variations in section and consequent uncertainty in interpretation.

## Radiography of Castings

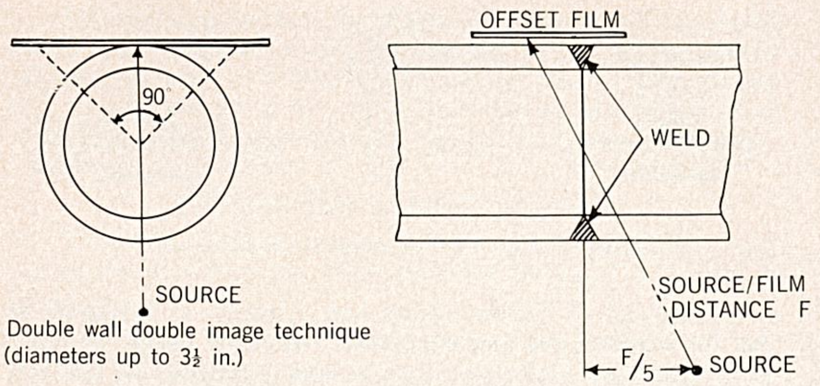
The major problems associated with the radiography of castings arise from their shape and variations in section.

(a) In complex sections there is usually some difficulty in covering all parts of the specimen. Unless particular attention is given to positioning the specimen and orienting the beam, some areas containing defects may be missed.

(b) Where thickness varies appreciably, some parts of the film may be under- or over-exposed. This can be minimised by:

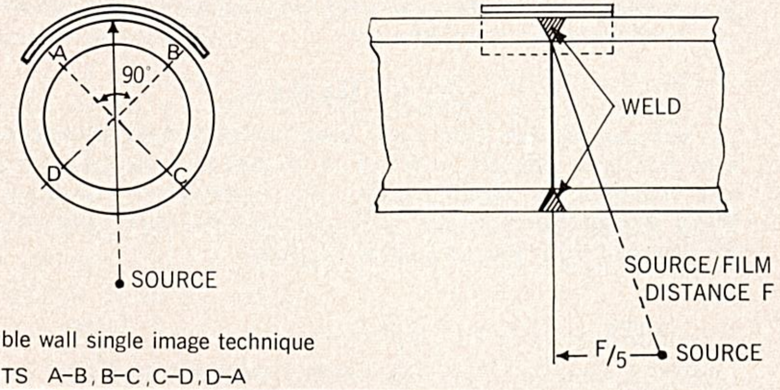
- (i) deliberately reducing contrast by using filters between the source and object to harden the beam,
- (ii) using blocking media (section equalisation techniques),
- (iii) using two or more films with different response speeds.

Techniques for flat plates are similar to those used for butt welds, the incident beam of gamma-rays being normal to the surface and passing through the minimum dimension. This technique also applies for castings which consist essentially of angular sections, such as L and T shapes (Figure 9). In these cases, however, it is important to pay particular attention to junction areas and this requires additional exposures.

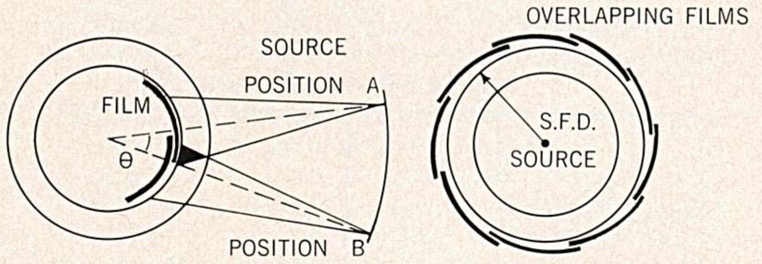


(a) Double wall double image technique (diameters up to 3½ in.)

FOR THICK TUBES ROTATE 90° FOR 2nd SHOT



(b) Double wall single image technique
4 SHOTS A–B, B–C, C–D, D–A



N.B. ANGLE θ MUST BE ADJUSTED SO SHADED OVERLAP AREA REACHES OUTSIDE OF PIPE

DISTANCE S.F.D. TO BE ADJUSTED FOR ADEQUATE DEFINITION

(c) Single wall single image technique (source outside)

(d) Single wall single image technique (source inside)

*Figure 7. Exposure technique for circumferential butt welds.*

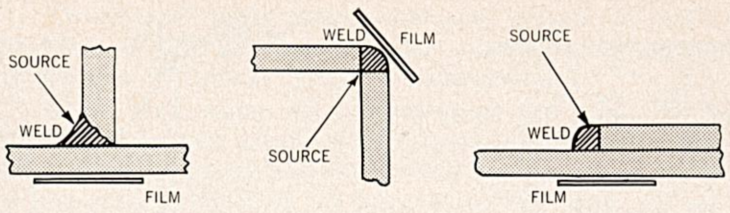


*Figure 8. Exposure technique for fillet welds.*

Treatment of hollow shapes and cylinders is analogous to that for welded tubes and the double wall-single image, or single wall-single image techniques may be used, depending on size and accessibility of the subject.

Spheres and solid cylinders comprising the whole or portion of a casting generally prove difficult subjects for radiography because of the difficulty of securing adequate film contact with the specimen and resultant poor edge definition.

## USE OF MARKERS

For correlation, the area being radiographed is normally identified with painted, punched or etched numerals. Equivalent lead numbers are placed on the film immediately above these. When welded structures are large and complex, each weld should be identified by a special number or letter.

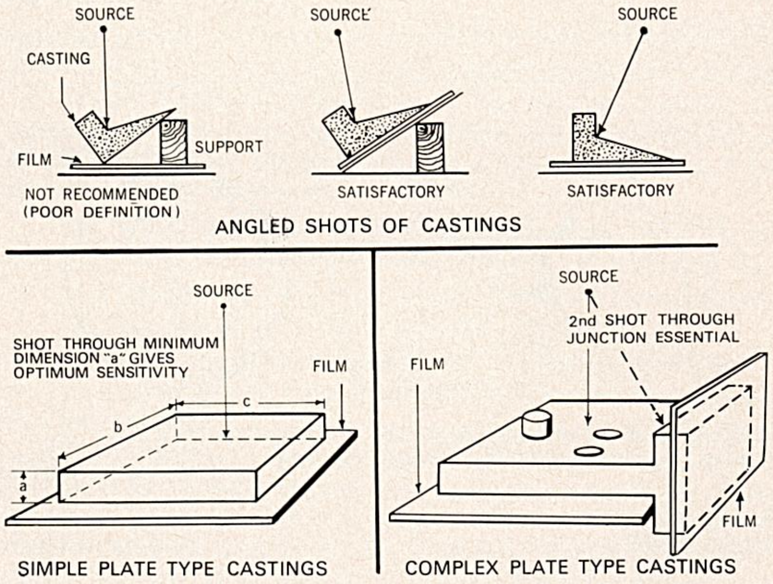


*Figure 9. Exposure technique for castings.*

For welds, particularly those ground to the level of the parent metal, the fusion zone should be identified by placing lead arrow markers just clear of it. Where a long seam is being radiographed it is normal practice to have a one inch overlap of adjacent films. Areas of special interest can also be indicated with lead arrows.

## PRECAUTIONS AGAINST SCATTER

The use of lead screens for image intensification and prevention of scatter has been described on page 13. Scatter is produced:

(a) Within the object being radiographed; and

(b) By reflection from objects near the specimen being radiographed, for example, cassettes, walls, table, etc.

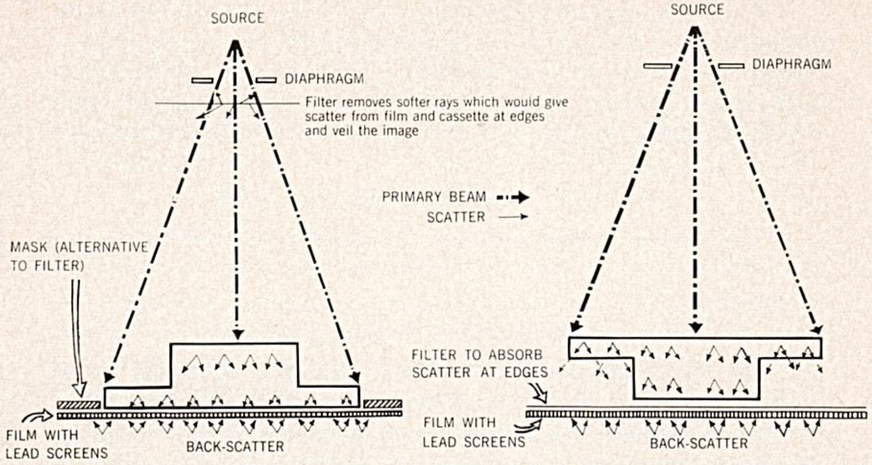
Scatter lowers the contrast and definition of the image by producing a general background of radiation which carries no coherent image. Scattered radiation may be reduced by using the following precautions.

(a) A diaphragm or attenuation muff (Reference 5) can be used to ensure that primary beam diameter is restricted to that of the object under examination. This prevents reflection of the beam by adjacent objects.

(b) A mask of lead sheet can be placed around the specimen being radiographed to shield other parts of the cassette, or film, not covered by the article and thus prevent them from becoming sources of scattered radiation.

(c) Lead filters or screens can be used in three positions:

- (i) *Immediately behind the film.* To prevent "back-scatter" from the surface on which the specimen is resting.
- (ii) *Between the specimen and the film.* This is the most effective position for absorbing scattered radiation produced within the specimen.
- (iii) *Between the source and the object.* If a lead filter is placed between the source and the specimen, the "softer" rays will be eliminated. This is suitable where the edges of the specimens have to be radiographed, and are in contact with the cassette. If the shape of the object is such that its filtration of the primary beam is small (Figure 10a) a large amount of scattered radiation is produced in the cassette and film, and, spreading sideways, will veil adjacent areas. This technique is more effective for sources with a wide range of energies such as iridium 192 and thulium 170. Though used previously for X-rays it could also be applicable



(a) SPECIMEN EDGES CLOSE TO FILM (b) SPECIMEN EDGES AWAY FROM FILM

*Figure 10. Use of masks and filters.*

to gamma-rays but some sources such as caesium 137 are either monochromatic or have similar principal energies, for example cobalt 60. Where the edges of the specimen are not too close to the film (Figure 10b) it is preferable to place the filter between the specimen and the film to absorb radiation due to strong scattering of the primary beam from the edges.

## Blocking Media

Where the primary beam passes through considerable variations in thickness of the object being radiographed, it is necessary to use "section equalising" techniques to avoid over-exposure of the film behind thin sections, and to avoid obscuring the edge as a result of radiation scatter. The thinner sections are built up by adding a medium of similar density. The techniques include:

(a) Holding the object in a cradle or surrounding it by thin strips or shot in a material with the same absorption characteristics as the object being radiographed (Figure 11).

(b) Immersing the object in liquid of suitable density such as organic halogen derivatives and solutions of lead salts (Figure 11).

## CHOICE OF CASSETTE TYPE

The following types of cassette are available:

(a) *Rigid type.* In effect a light-tight flat box made of cardboard, thin metal or other material to protect the film from light without seriously reducing intensity of the incident radiation.

(b) *Flexible type.* Made of thin plastic or rubber, a common example being two open-ended envelopes, one of which fits inside the other.

(c) *Evacuable type.* Fitted with an air valve connection so that it can be evacuated to ensure good contact between cassette, screens and films.

The choice of cassette is based on type, shape and thickness of the specimen. A rigid type is used for heavy work, castings and thick weldments in steel, etc. Thin flexible cassettes are used for thin sections and light alloys (as they absorb less radiation) and for curved sections (inside and outside of tubes).

## CHOICE OF FILM TYPE

Most films used for gamma radiography are of the "non-screen" type. The term "screen" in this context means the fluorescent salt screens which are used in medical and occasionally is industrial radiography. Films used with such screens are "grainy" and have relatively high $U_f$ (film unsharpness) values (see page 22).

Non-screen films for gamma radiography can be divided into three classes:

(a) Ultra-fine grain, high contrast type,
(b) Fine grain, high contrast type,
(c) Medium speed type.

Most manufacturers of X-ray and gamma-ray film supply types which fit the above categories. The films together with their more important properties are listed in Table 3.

The film used will depend on the type of defect to be revealed, and section, shape and composition of the specimen. The technique is sometimes specified in the appropriate code of practice and

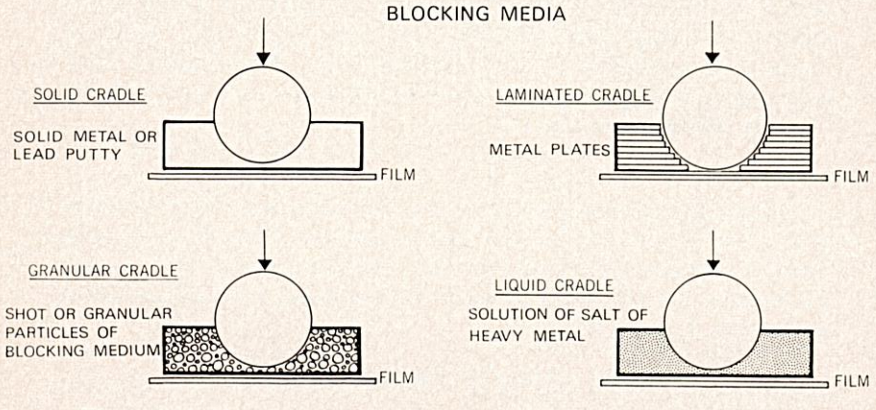


*Figure 11. Section equalisation techniques — cylindrical and spherical sections.*

## TABLE 3

## DATA ON COMMERCIALLY AVAILABLE FILMS* USED IN RADIOGRAPHY

| Film | Manufacturer | Grade | Comparative Speed |
|---|---|---|---|
| | | | Gevaert D10 = 1 |
| Ultra fine grain | Kodak | Microtex | 16 |
| High Contrast | Ilford | F | 12.5 |
| Direct Type | Gevaert | D4 | 16 |
| | Ansco | — | — |
| Fine Grain | Kodak | AA | 4 |
| High Contrast | Ilford | C<br>CX | 7<br>4 |
| Direct Type | Gevaert | D7 | 4 |
| | Ansco | Type A<br>Type B | 3<br>3 |
| | Kodak | Industrex D | 1.8 |
| Medium Speed | Ilford | B<br>G | 1.8<br>0.6 |
| Direct Type | Gevaert | D10 | 1 |
| | Ansco | Type C | 1 |

There are no sharp distinctions between the three main categories listed in Column 1 and the table is for general guidance and information. A number of other available films may be used.

* *Some of these films may not be available in Australia.*

advice on this aspect is also available in a number of specifications relating to radiography (BS2600: 1962, see Appendix). When in doubt it is preferable to use ultra-fine grain, high contrast film, particularly with the higher energy radioisotopes such as cobalt 60, caesium 137 and iridium 192.

### Lead Screens

Lead screens are invariably used in radiography with isotopes other than for the low energy gamma emitters, that is, those with photon energies less than 80 keV. Recommended lead screen thicknesses for the most popular radioisotope sources are given in Section 1, page 13.

## IMAGE QUALITY INDICATORS (IQI)

Image Quality Indicators, or penetrameters, provide an indication of defect sensitivity only to the extent that their features

simulate a given type of defect. The most common types available are:

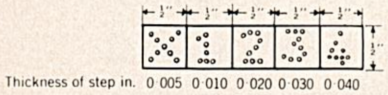
(a) *Step wedge types.* The British Welding Research Association (BWRA) type has graded steps of the same material as the specimen to be radiographed. Each step is $\frac{1}{2}$ in. square and differs from its neighbour by 0.010 in. (0.005 in. for the first step). Each step is drilled with holes to indicate its serial number (Figure 12a). The American Society of Mechanical Engineers (ASME) type is similar to the BWRA type but each step has a 3/16 in. diameter hole in the centre of each step instead of the serial number (Figure 12b). In addition, single thickness American Petroleum Institute (API)/ASME penetrameters are available equivalent to 2% of the section being radiographed. Holes equal to two, three and four times the thickness are drilled in the plate.

(b) *Wire type.* The DIN type of penetrameter has seven wires (diameter increasing from right to left) embedded in plastic or rubber. The range of wire diameters depends on the thickness being examined (Figure 12c).

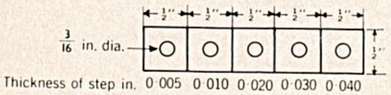
Two types of DIN image quality indicator are available. In the DIN 54.110 system, the wire diameters increase in arithmetic progression. A set of four image quality indicators will provide wires in the thickness range 0.1 to 4 mm. In the DIN 54.109 system, the wires increase in geometric progression and a set of three such indicators provides wires in the thickness range 0.1 to 3.2 mm.

## EXPOSURE CHARTS

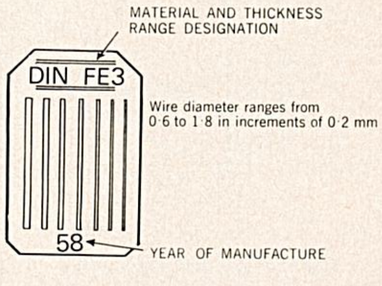
Exposure conditions in radiography using radioisotopes are normally determined from the operator's experience using his existing records, but frequently this may be wasteful of film and operating time. Therefore, it is advantageous to compile exposure (or technique) charts specific to each type of radioisotope and the material(s) with which it is likely to be used.



(a) BRITISH BWRA TYPE



(b) AMERICAN API — ASME STEP TYPE



(c) GERMAN DIN TYPE (54-110 SYSTEM)

*Figure 12. Types of image quality indicators (penetrameters).*

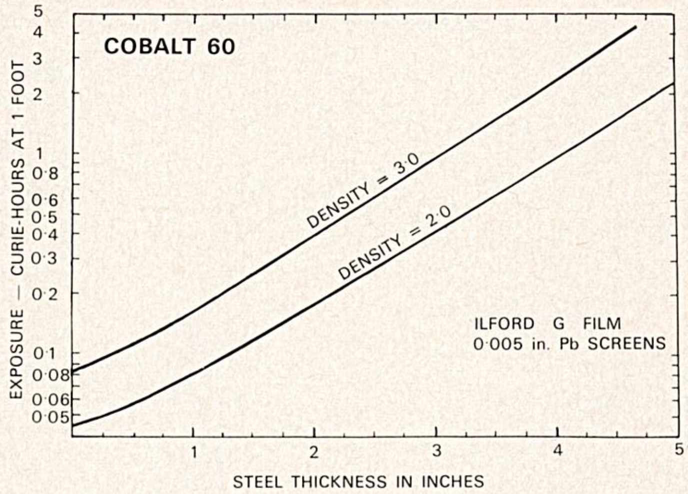
The main variables in gamma radiography of simple sections are:

(a) Mass or linear absorption coefficient.
(b) Specimen thickness.
(c) Energy of the radiation.
(d) Source strength.
(e) Exposure time.
(f) Source to film distance.
(g) Film speed.
(h) Processed film density.

Exposure charts relate exposure time to thickness and, for convenience, other variables are kept constant. Thus, (a) and (c) can be determined by the subject material and type of radioisotope being used, and the effect of variations in source strength, source to film distance, film speed and processed film density can be allowed for and adjustments made by simple formulae.

Exposure curves are prepared by making a series of radiographs of step wedges at a constant source to film distance (usually 36 in.). From densitometer readings, thickness and density curves are then plotted for a number of exposure times. In the final curves the thickness corresponding to the required density is plotted against exposure time. This may be expressed in curie-hours or directly in roentgens. Figure 13 gives exposure charts for cobalt 60, caesium 137, caesium 134 and iridium 192 with steel, and thulium 170 with aluminium (Reference 6).

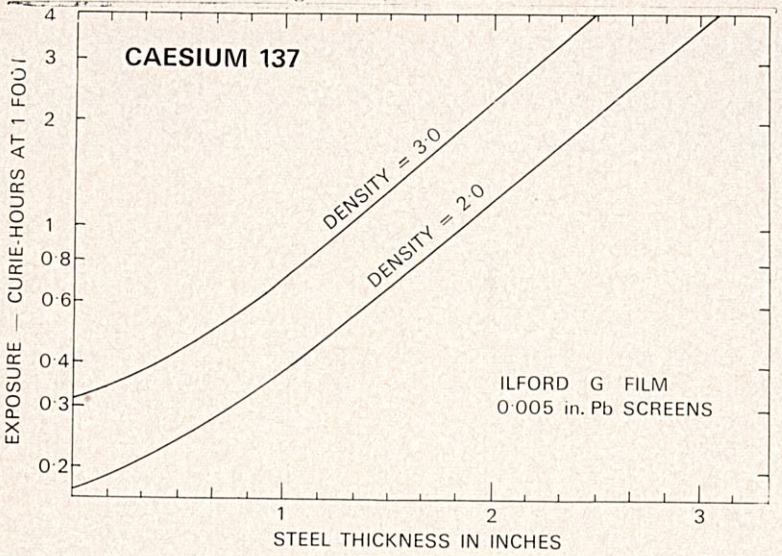
*Figure 13 (Below and pages 33-34). Radiographic exposure curves.*



*(a) Cobalt 60 with steel.*

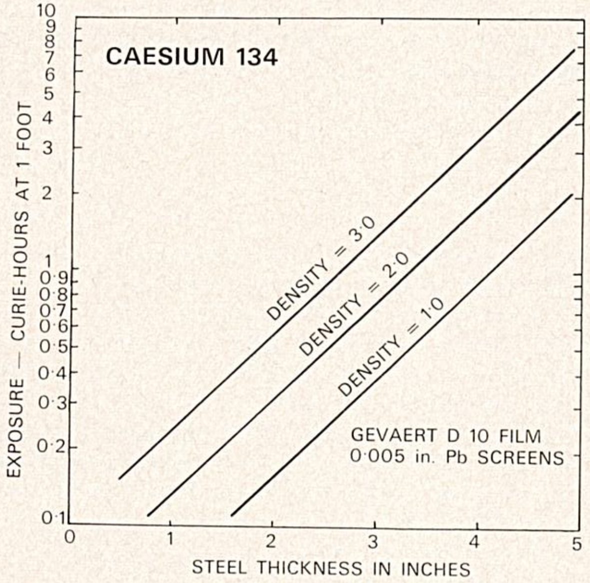
$$\text{Exposure required} = \frac{\text{curie hours x (ft)}^2}{\text{curie strength}} \text{ x } \frac{\text{film speed factor (Table 3)}}{0.6}$$

*Figure 13, continued*



*(b) Caesium 137 with steel.*

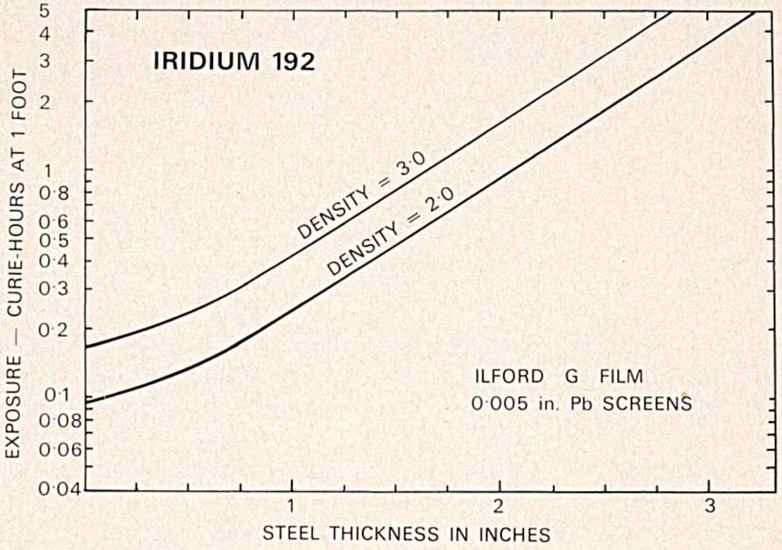
$$\text{Exposure required} = \frac{\text{curie hours x (ft)}^2}{\text{curie strength}} \text{ x } \frac{\text{film speed factor (Table 3)}}{0.6}$$



*(c) Caesium 134 with steel.*

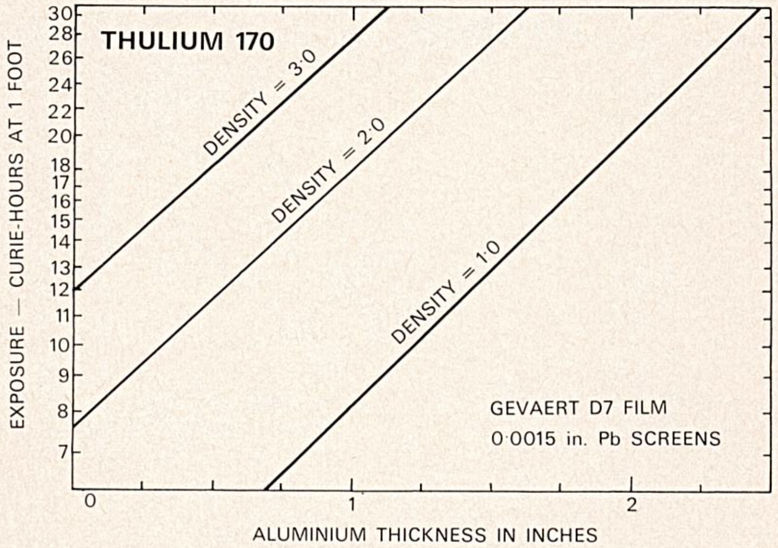
$$\text{Exposure required} = \frac{\text{curie hours x (ft)}^2}{\text{curie strength}} \text{ x film speed factor (Table 3)}$$

*Figure 13, continued*



*(d) Iridium 192 with steel.*

$$\text{Exposure required} = \frac{\text{curie hours x (ft)}^2}{\text{curie strength}} \text{ x } \frac{\text{film speed factor (Table 3)}}{0.6}$$



*(e) Thulium 170 with aluminium.*

$$\text{Exposure required} = \frac{\text{curie hours x (ft)}^2}{\text{curie strength}} \text{ x } \frac{\text{film speed factor (Table 3)}}{6.6}$$

## Section 4

# VIEWING AND INTERPRETATION OF RADIOGRAPHS

### VIEWING CONDITIONS

Radiographs should be examined in a darkened room using a screen which is uniformly illuminated by diffused light. The area of the viewer surrounding the film should be masked. Brightness of the radiograph should be at least 1 candela/ft$^2$, and preferably as high as 10 candelas/ft$^2$. Since the density of the radiograph (Section 1, page 10) may be as high as 3.0, the brightness of the viewing screen for satisfactory interpretation should be at least 1,000 candelas/ft$^2$, and preferably as high as 10,000 candelas/ft$^2$.

Viewing screens may need to be cooled to avoid damaging the film by heat. A low-power magnifying glass (x5) is useful.

### PRELIMINARY ASSESSMENT OF RADIOGRAPH

#### Adequate Density

A preliminary examination of the radiograph will show whether the density is adequate. A value within the range 2.0 to 3.0 generally is considered satisfactory. For subjects of uniform thickness, welds for example, the density of the radiograph should be uniform, but portions of radiographs of non-uniform sections, such as castings (Section 3, page 24), may not always be within prescribed limits.

#### Penetrameter Sensitivity

The types of penetrameter (image quality indicator) in general use were discussed on page 30. The IQI sensitivity value is determined in the case of BWRA penetrameters by finding the size of the smallest step with the identity figure visible (or for DIN penetrameters, the smallest diameter wire visible), then dividing by the section thickness and multiplying by 100. It is important that step-type penetrameters should not obscure areas where defects are likely to be found, welds for example, and that wire-type penetrameters should be placed with the wire across the weld.

The required sensitivity is usually given in the "codes of practice" (see Appendix) and a value of 2% is typical.

#### Film Processing Defects

The production of satisfactory radiographs depends on proper processing of the exposed film. Many types of spurious defect indication may be caused by unsound darkroom practice. The main types are:

(a) *Grey fog*, due to defective or excessive use of safe-lights, old film and/or exhausted or aged developer.

(b) *Dichroic fog*, (yellow-green in colour) due to developer which is exhausted or contaminated by fixer, or incomplete removal of developer in the wash or stop bath.

(c) *Clear spots*, due to air bubbles adhering to film during development; spots of fixer on the film before development; local areas of heavy pressure, or irregular drying of the film.

(d) *Streaking*, in the form of bromide streaks caused by insufficient agitation during development, or streaks of fixer or stop bath solution running down the inclined film before development.

(e) *Dark spots*, caused by spots of water or developer getting on the film before development, pressure or drying spots, or static electricity discharges under conditions of low humidity.

## ASSESSMENT OF DEFECTS

The radiographer should be familiar with the basic technology of production of the components under examination. Familiarity with type and location of expected defects is useful. It is important to be able to relate to its origin the radiographic image of a possible defect in the object, by understanding the nature of transmission of radiation through varying sections and media of different density and the production of images.

The radiographer should have access to the component being examined and to copies of the relevant drawings giving details of weld preparation, etc.

### Location of Defects in Specimens

As a radiograph is essentially a two-dimensional image, it gives no indication of the position of a defect in the direction of the incident beam. When a preliminary examination has revealed a defect, it may be necessary to locate it to assess its effect on the serviceability of a component and determine whether it can be repaired. The following procedures may then be used.

(a) For defects in thick compact prismatic sections such as castings, etc., make two exposures at right angles to each other if possible (Figure 14a).

(b) For defects in comparatively thin flat objects, use the source shift method which involves making two images on the same film. The initial exposure is made using only half the normal time for the material and thickness (obtained from appropriate chart). The radioisotope source is then moved a predetermined distance parallel to the film and the second exposure made for half the normal time. Image separation can be measured and the defect depth determined by simple geometry (see Figure 14b).

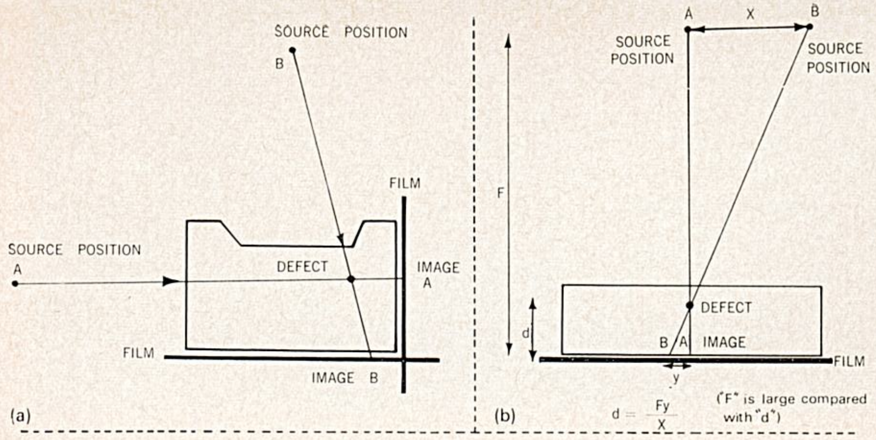


*Figure 14. Location of defect position.*

### Defects in Castings

Detailed discussion of defects in castings is not possible in this manual. The various specifications and reference radiographs should be consulted (see Appendix). However, the important features of the main types of casting defect are summarised below.

(a) Gas porosity which appears as well defined black specks and is due to evolution of hydrogen on solidification, furnace gases, or air bubbles in the moulding sand.

(b) Shrinkage porosity which appears as diffuse dark areas and is caused by faulty casting techniques such as low pouring temperature, risers being too small or badly placed, etc.

(c) Inclusions which appear as defects of lower density than pores, and may be caused by sand from the mould coating or slag from oxidised metal.

(d) Hot tears which appear as comparatively wide cracks. They are formed when the metal is in the plastic stage and are due to stress concentration caused by inadequate fillets, or wide variations in the cooling rate and mould resilience during solidification.

(e) Cracks formed by mechanisms similar to those described in (d) but tending to occur when the metal is in the elastic range.

(f) Cold shuts which may appear as linear defects. They are formed in areas where two streams of molten metal converge but do not fuse or are adjacent to unfused chaplets or chills.

(g) Segregation may occur in alloys due to constituents having different solidification characteristics. Segregation appears as areas of varying density.

(h) Surface defects such as scales and swells which are usually caused by mould surface defects.

### Defects in Welds

For complete details of weld defects, reference should be made to standard specifications and collections of reference radiographs. The main types of defect likely to be encountered are:

(a) Porosity. Pores appear as sharply defined dark specks. They are caused by entrapment of gas evolved during solidification.

(b) Pipes which appear as sharply defined dark areas but appear elongated.

(c) Slag inclusions which may be globular or linear and appear as areas of intermediate density. They are caused by entrapped slag.

(d) Lack of fusion which appears as a thin dark line with well-defined edges when the beam of radiation is parallel to the plane of the defect. When the beam is not parallel to that plane, the appearance of the defect is diffuse.

(e) Incomplete penetration which appears as a dark continuous or intermittent line in the middle of the weld.

(f) Cracks which may be transverse or longitudinal.

(g) Undercut caused by burning away the edge of the parent metal in the welding arc. It appears as a broad and diffuse dark line at the edge of the weld.

## RECORDS

In operating a radiography laboratory, it is essential to keep adequate records which consist essentially of details of technique and reports on defects, etc.

(a) *Technique*. The relevant details of technique to be recorded are:
  (i) Material.
  (ii) Thickness (range).
  (iii) Component details including Drawing Number.
  (iv) Radioisotope type, source strength and diameter.
  (v) Source to film distance.
  (vi) Film type.
  (vii) Lead screens.

(b) *Nature of defects*. Records should be made of:
  (i) Film identity number.
  (ii) Type of defect. For castings and welds this may be indicated by a symbol.
  (iii) Position of defect.
  (iv) Remarks.

A selection of radiographs obtained by gamma radiography is shown in Plates 5-8.

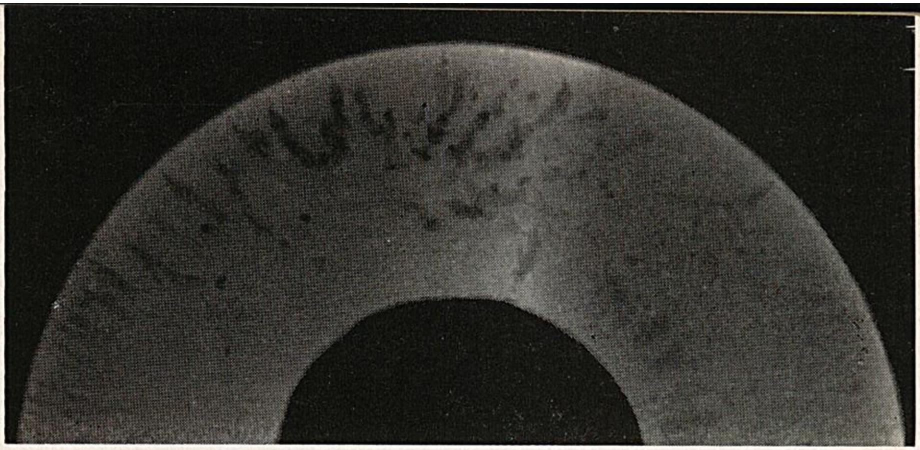


*Plate 5. Above: Radiograph of a casting of a low pressure steam flange, in molybdenum alloy steel, showing worm holes. Average thickness 5/8 in., Gevaert D7 film.*

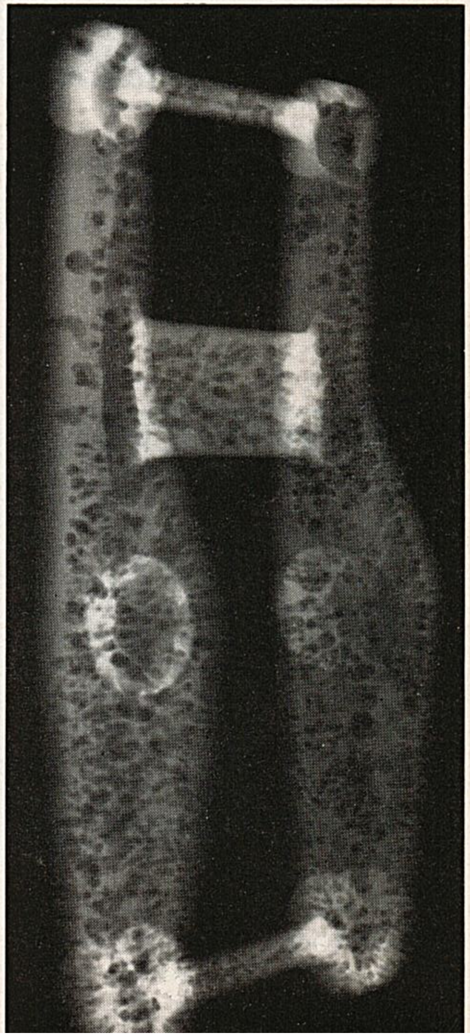


*Plate 6. Right: Radiograph of a steel hanger casting showing gas holes. Average thickness ½ in., iridium 192, 9.5 Ci h, source - to - film distance (SFD) 24 in., Gevaert D4 film.*

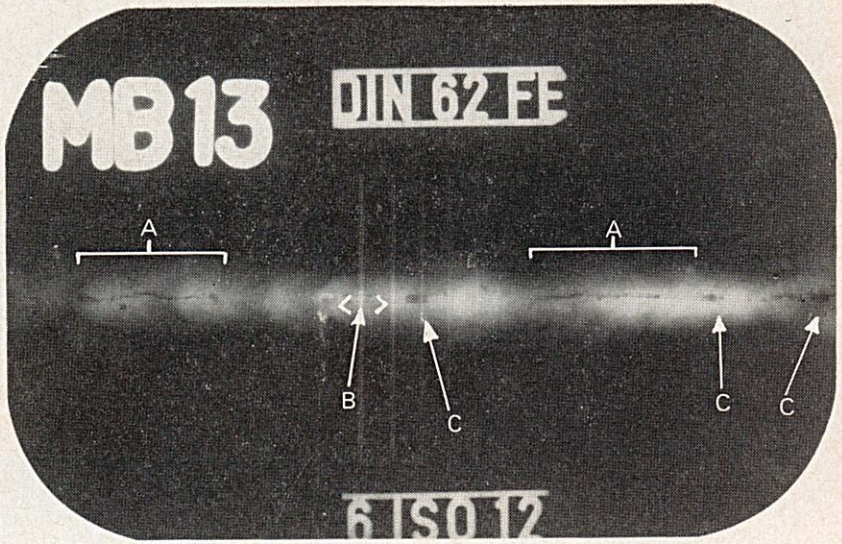


*Plate 7. Radiograph of manual arc butt weld in 3/8 in. mild steel plate showing the following defects: (A) Longitudinal cracks in root of weld. (B) Lack of root fusion (on one side of the vertical face or land of weld preparation). (C) Incomplete root penetration.*

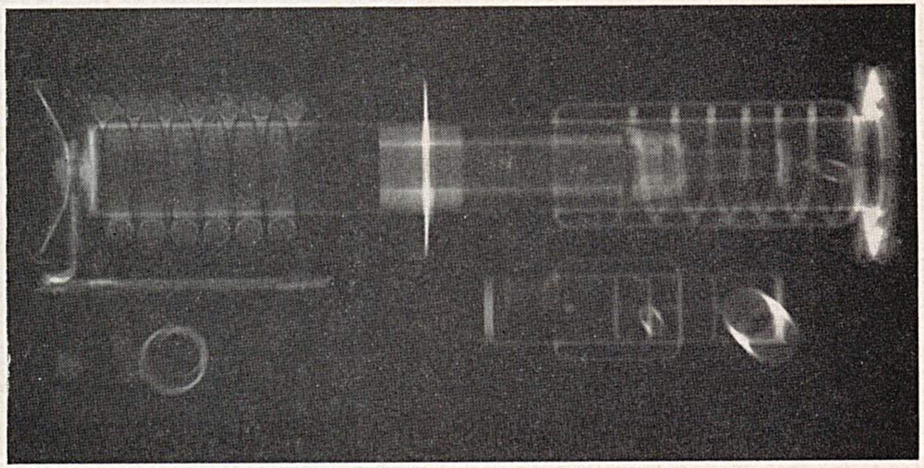


*Plate 8. Radiograph of a mercury vapour diffusion pump. Average thickness 5/16 in., iridium 192, 8.5 Ci h, SFD 24 in., Gevaert D4 film.*

## Section 5

# RADIATION PROTECTION

## METHODS OF ENSURING PROTECTION

In common with other forms of ionising radiation, gamma-rays have a harmful effect on the human body and exposure must be prevented or reduced to a minimum. In practical radiography, it is not possible to prevent exposure to gamma-rays entirely and the concept of an acceptable or maximum permissible dose is now universal.

The legislation and codes of practice of most countries (based on the recommendations of the International Commission for Radiological Protection) are very similar. Reference should be made to the appropriate regulations in force in each Australian State (Reference 2 and 4 and Appendix).

To establish exposure standards, the population is classified into groups related to possible exposure conditions. It can be stated broadly that persons "occupationally exposed", radiographers for example, should not receive a whole body dose of more than 3 rem (see Glossary) in any period of 13 consecutive weeks or more than 5 rem in any year.

The three fundamental methods of ensuring protection by minimising exposure are:

(a) Minimising the time spent near the radiation source.

$$\text{Allowable working time (in hours per week)} = \frac{\text{permitted exposure (milliroentgen/week)}}{\text{dose rate in milliroentgen/h}}$$

(b) Reducing the dose received by ensuring that the operator keeps at an adequate distance from the source. If the dose rate at a distance of one foot is known, the dose rate at any distance can be found by using the inverse square law.

(c) Providing suitable shielding material between the operator and the source.

## MONITORING INSTRUMENTS

### Personal Monitoring

The film badge and pocket dosimeter (Q.F.E.) are the usual monitors of radiation dose absorbed by personnel. The film badge is a strip of radiation-sensitive film in a plastic container which has "windows" with filters which absorb some types of radiation and transmit others. Thus, when the film is processed, it is possible to calculate the levels of exposure to different types of radiation, for example, slow neutrons, beta, gamma and X-rays.

(Slow neutrons and beta-rays are not normally encountered in industrial radiography.)

Films from the badges are usually processed at intervals of two or four weeks and a cumulative record kept of results. The film badge should be worn on the front of the chest pinned to the outer garment and not covered by clothing or other material. Film dosimeters which are not in use must be stored so that they will not be exposed to radiation, moisture, heat and chemical dust or fumes. In addition, the film dosimeter cassette must not be opened nor the position of the film in the cassette altered.

In spite of its robustness, convenience and provision of a permanent record, the film badge has disadvantages, the most obvious being that it cannot immediately indicate dangerously high dose rates Owing to the time that must elapse before the film is processed it may be difficult to establish the cause of an unexpectedly high dosage and the exact time and place of occurrence.

Consequently it is desirable to use pocket dosimeters of the quartz fibre electrometer type as a supplementary aid for immediate indication of absorbed dose on a visible scale. In addition, a number of other types of personal monitors are available which incorporate visual or audible alarms and thus indicate immediately when the dose rate exceeds a preset value.

### Area Monitoring

The operator also needs to have a radiation monitor, usually of an ionisation chamber type, to check dose rate in the area immediately surrounding the job site to verify that the source has been returned to its shielded container immediately following the radiograph. For field radiography, provision of a monitor is essential to ensure that rope barriers and warning signs are erected at the correct distance from the source for the information of staff working in the area.

## PROVISION FOR SHIELDING IN RADIOGRAPHY LABORATORIES

The appropriate type and thickness of shielding for radiography laboratories can be calculated from the formula:

$$B = \frac{0.1}{WUTD}$$

where:

B is the *transmission factor* through the shielding medium to reduce the radiation dose to the permitted level of 100 millirem/week.

W is the *workload*, i.e. the number of hours per week the source is likely to be exposed.

U is the *use factor* which represents the proportion of the time the beam is directed at the area being considered. In the absence of precise information obtained from monitors, the following values of U may be taken:

In front of beam ........ U = 1
At right angles to beam ........ U = 1/4
In a direction opposite to the beam ........ U = 1/16

T is the *occupancy* factor, i.e. the proportion of the working week spent in the area under consideration. It is impossible to determine this factor accurately and arbitrary values must be assigned as follows:

Control areas, dark rooms, viewing rooms ........ T = 1
Corridors, change rooms, etc. ........ T = 1/4
Stairways, toilets, etc. ........ T = 1/16

D is the dose rate which is calculated from the formula:

$$D = \frac{KC}{d^2}$$

where K = specific gamma emission constant in roentgens/h/curie at 1 ft. Typical values for K are:

| | |
|---|---|
| Tm170 | 0.023 |
| Cs137 | 3.6 |
| Ir192 | 6.0 |
| Co60 | 14.8 |

C = source strength in curies.

d = distance in feet (from source to "point of interest").

Once the transmission factor has been calculated, it is possible to determine the appropriate thickness of absorber from the attenuation curves relevant to the radiation source being used (Reference 7). For example, for cobalt 60 if the value of B = 0.001, 27 inches of concrete will be required.

## SUMMARY OF CODE OF SAFE PRACTICE WHEN USING RADIOISOTOPES FOR RADIOGRAPHY

(i) Always wear film badges and pocket dosimeters in the working area.

(ii) Allow only persons into the working area who are authorised for occupational exposure.

(iii) Keep adequate records to show the location of radioactive sources at all times.

(iv) Label all storage containers and exposure containers with details of the radioisotope they contain, for example, Isotope, Source size, Activity, Date, Identity number.

(v) Provide all exposure containers with a locking device to prevent unauthorised removal or exposure of the source.

(vi) See that the maximum radiation dose at the surface of the radioisotope storage container does not exceed 200 milliroentgens/hour. The exposure dose rate at a distance of one metre from the centre should not exceed 10 milliroentgen/hour.

(vii) When the radioisotope source is not in use, store it in such a way as to prevent unauthorised persons having access to it. The maximum exposure dose to any unauthorised person under storage conditions should not exceed 1 milliroentgen/hour or 10 milliroentgens/week.

(viii) Never hold sources directly in the hand. (If the specific gamma emission constant is known, the dose rate at the source surface can be found using the inverse square law.)

(ix) Never tamper with source capsules. At the end of an exposure the operator should verify that the source has been returned to its container by using an appropriate survey monitor.

## References

1. British Welding Research Association (1958). The Radiographic Examination of Welds in Mild Steel Plates by X and $\gamma$-Rays. *British Welding Journal* 5 (5): 244-247.
2. New South Wales Department of Public Health. Division of Occupational Health. *Code of Practice for Industrial Radiography.*
3. GREEN, F. L., CHEEK, W. D., BLACK, R. E., GRAHAME, G. P. (1960). Samarium 145, Samarium 153, Gadolinium 153 and Thulium 170 Sources for Radiography. *Non-Destructive Testing* 18 (6): 382-389.
4. New South Wales *Radioactive Substances Act* (1957).
5. CHRIMES, N. W. D. (1965). Radioactive Source Cameras for Industrial Radiography. *Testing, Instruments and Controls* 2 (10): 9-14.
6. GILLESPIE, P. A. Radiographic Exposure Charts for Radioisotope Sources, AAEC/TM460.
7. New South Wales Department of Public Health. *Radiation Protection in Industry.*

## Appendix

# BIBLIOGRAPHY, CODES AND SPECIFICATIONS, AND TRANSPORT REGULATIONS

## Bibliography

McMaster, R. C. *Non-Destructive Testing Handbook*, Vol. 1 and 2, Ronald (1959).

Halmshaw, R. *Physics of Industrial Radiology*, Heywood (1966).

Rockley, J. C. *An Introduction to Industrial Radiography*, Butterworth (1964).

Crowther, J. A. *Industrial Radiology*, Edward Arnold (1949).

Wiltshire, W. J. *A Further Handbook of Industrial Radiography*, Edward Arnold (1957).

Rumyantsev, S. *Industrial Radiology, the Use of Radioactive Isotopes in Flaw Detection.* Foreign Languages Publishing House, Moscow (1963).

International Institute of Welding (1961). *Handbook on Radiographic Apparatus and Techniques.*

Kodak Limited, London. Kodak Data Sheets.

Agfa Gevaert. *Industrial Radiography.*

Ilford. *Technical Information Book*, Vols. 1 and 2.

The Institute of British Foundrymen (1961). *Atlas of Defects in Castings.*

## Codes and Specifications

American Society Mechanical Engineers, Boiler and Pressure Vessel Code Sec. 8 (1968).

Standards Association of Australia, Code CB1 (1954), SAA Boiler Code, Part V, Welding.

Standards Association of Australia, Australian Standard B164, 1965. Radiographic Examination of Fusion Welded Circumferential Butt Joints in Steel.

Standards Association of Australia, Australian Standard B230, 1967. Radiographic Examination of Fusion Welded Circumferential Butt Joints in Steel Pipes.

Standards Association of Australia, Australian Standard B237, 1967. Radiographic Examination of Fusion Welded Butt Joints in Light Alloys.

Standards Association of Australia, Australian Standard Z5, 1958. Glossary of Welding Terms and Definitions.

British Standards Institution, British Standard 1500, 1958. Fusion Welded Pressure Vessels for General Purposes. Part 1, Carbon and Low Alloy Steels.

British Standards Institution, British Standard 4097, 1966. Specification for Gamma Radiography Exposure Containers for Industrial Purposes and Their Source Holders.

British Standards Institution, British Standard 3513, 1962. Specification for Gamma Radiography Sealed Sources.

British Standards Institution, British Standard 3895, Part 1, 1965. Methods for the Assessment of Packaging for the Transport of Radioactive Materials.

British Standards Institution, British Standard 2600, 1962. Radiographic Examination of Fusion Welded Butt Joints in Steel.

British Standards Institution, British Standard 2910, 1965. General Radiographic Examination of Fusion Welded Circumferential Butt Joints in Steel Pipes.

British Standards Institution, British Standard 3451, 1962. Methods of Testing Fusion Welds in Aluminium and Aluminium Alloys.

British Standards Institution, British Standard 499, 1952, Glossary of Terms (with Symbols) Relating to the Welding and Cutting of Metals.

British Standards Institution, British Standard 2737, 1956. Terminology of Internal Defects in Castings.

British Standards Institution, British Standard 4080, 1966. Methods for Non-Destructive Testing of Steel Castings.

### Regulations Related to the Carriage and Use of Radioisotopes

*International Air Transport Association (IATA)*

Regulations Relating to the Carriage of Restricted Articles by Air — 11th Edition effective 1 October, 1967, until further notice.

*Note:* Part I. Section 700, 701, 702, 703, 704.

*or*

Part II. (based on IAEA recommendations).

Regulations for the Safe Transport of Radioactive Material, 1967 Edition, Safety Series No. 6.

*New South Wales*

Regulations, Radioactive Substances Act 1957.

*South Australia*

Regulations under the Health Act 1935-1961.

Radioactive Substances and Irradiating Apparatus Regulations.

*Western Australia*

Radioactive Substances Act 1954-1960.

*Tasmania*

Radioactive Substances Regulations 1963.

*Queensland*

Queensland Government Gazette. Regulations under the Radioactive Substances Act of 1958.

*Victoria*

Victorian Government Gazette 1959. Regulations Relating to Irradiating Apparatus and Radioactive Substances.

*National Health and Medical Research Council, Canberra, A.C.T.*

Code of Practice for the Control and Safe Handling of Sealed Radioactive Sources used in Industrial Radiography.

*New Zealand*

The Radiation Protection Regulations (1951).

## GLOSSARY

### Definitions of Radiological Terms

1\. **The curie** is the measure of the disintegration rate of a source, and is defined as $3.7 \times 10^{10}$ disintegrations per second.

1\. **The roentgen** is that quantity of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of electricity of either sign. In air, this results in the absorption of 85 to 88 ergs of energy per gram of air.

3\. **The rad** is that quantity of radiation corresponding to the absorption of 100 ergs per gram.

4\. **The rem** is the measure of the dose to body tissues of any ionising radiation in terms of its estimated biological effect relative to a dose of 1 rad of X or gamma radiation.

5\. **The electron volt** is the kinetic energy acquired by an electron crossing a potential difference of 1 volt.

(1 keV = 1,000 eV, 1 MeV = 1,000,000 eV)

6\. **Monochromatic radiation** is radiation consisting of a single wavelength of quantum energy.

**Notes:**

---

Produced By
Australian Atomic Energy Commission Information Section,
45 Beach Street, Coogee, N.S.W.

Printed by J. Bell & Co. Pty. Ltd.

---

## INDUSTRIAL RADIOGRAPHY WITH RADIOISOTOPES

### - ADDENDA -

### CODES AND SPECIFICATIONS

Standards Association of Australia, Code CB1. S.A.A. Boiler Code, Part 1 (1962)

Standards Association of Australia, Code CB15, S.A.A. Pipe Welding Code, Part 3 (1967)

Standards Association of Australia, Australian Standard B259, 1968. Glossary of Terms used in Non-Destructive Testing. Part 3, Radiological Flaw Detection. (Being B.S.3683 Part 3 1964 endorsed as the Australian Standard subject to Australian Amendment No. 1)

Standards Association of Australia, Australian Standard B262, 1968. Image Quality Indicators for Radiography and Recommendations for their use. (Being B.S.3971 1966 endorsed as the Australian Standard without amendment)

Standards Association of Australia, Australian Standard Z5, 1968. Part 2. Terminology of and Abbreviations for Fusion Weld Imperfections as revealed by Radiography. (Being B.S.S.499 Part 3 1965 endorsed as the Australian Standard subject to Australian Amendment No. 1)

British Standards Institution, British Standard 1500,1965. Fusion Welded Pressure Vessels for General Purposes, Part 3, Aluminium

British Standards Institution, British Standard 1515. Fusion Welded Pressure Vessels for use in the Chemical, Petroleum and Allied Industries. Part 1 1965, Carbon and Ferritic Alloy Steels. Part 2 1968, Austenitic Steels

### REGULATIONS RELATED TO THE CARRIAGE AND USE OF RADIOISOTOPES

International Air Transport Association - Regulations relating to the carriage of restricted articles by air - 13th Edition effective 1st June 1970 until further notice.

International Atomic Energy Authority - Regulations for the Safe Transport of Radioactive Materials 1967 Edition, Safety Series No. 6.

New South Wales - Radioactive Substances Act 1957. Radioactive Substances Regulations 1959 (as amended).

South Australia - Regulations under the Health Act 1935-1961. Radioactive Substances and Irradiating Apparatus Regulations.

Western Australia - Radioactive Substances Act 1954-1960. Radioactive Substances Regulations 1958 (as amended).

Tasmania - Radioactive Substances Act 1954 (and amendments). Radioactive Substances Regulations 1963.

Queensland - Radioactive Substances Act 1958. Radioactive Substances Regulations 1961.

Victoria - Health Act 1958 (and amendments). Irradiating Apparatus and Radioactive Substances Regulations 1959.

August 21, 1970