INDUSTRIAL RADIOGRAPHY

A Teaching Syllabus and Some Recommended Practical Experiments and Exercises.

Prepared by J. C. Rockley

United Nations Development Programme
Project N°ARG/71/537
Constituyentes Atomic Energy Centre
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PREFACE

The purpose of this teaching syllabus is to provide a resumé of the minimum amount of information that is considered to be necessary for the instruction of students who are required to take an active part in the use of industrial radiography, or in the running of an industrial radiographic department. The time required to cover the full syllabus and to complete the practical experiments is about 140 hours. Extra time should be allowed for the completion of the additional exercises on "real life" specimens.

The full syllabus is intended for use in the instruction of students who are already professionally qualified in a science or engineering discipline appropriate to quality assurance. However, by extracting from the main syllabus it is possible to use it for the instruction of technicians and operators who require a limited knowledge of certain aspects of industrial radiography.

No two lecturers will teach a given subject in an identical manner, although at the end of the course they will have covered more or less the same subject matter. In following this syllabus, therefore, the linking up of certain topics could be varied from the pattern suggested. However, the sequence adopted has been found to be logical and generally acceptable in practice. The depth of instruction must be left to the discretion of the individual lecturer who should adapt his treatment of the subject to the aims of his course and the academic level of the students. Perhaps the most important point to remember is that industrial radiography is essentially a very practical subject. Care should be taken, therefore, to retain the correct emphasis on the practicalities involved and not to turn the course into a series of lectures on nuclear physics and electronic engineering.

J. C. Rockley

J. C. ROCKLEY

Buenos Aires, September 1977.

JCR/ENB

TRAINING COURSE IN INDUSTRIAL RADIOGRAPHY.

THEORY

Part 1: THE NATURE OF AN INDUSTRIAL RADIOGRAPH.

1. The Construction of Radiographic Film.

1.1. Types of photographic emulsions: blue-sensitive, orthochromatic, panchromatic; spectral sensitivity.

1.2. Radiographic film as a "blue-sensitive" emulsion; classification of radiographic film into "screen" and "non-screen" types. Sensitivity of radiographic film to electro-magnetic radiations, particulate radiations, mechanical pressure.

1.3. Construction of radiographic film: nature, thickness, and dimensional stability of central support; "double coated" radiographic film, advantages of double-coated film; emulsion composition and thickness; emulsion graininess.

2. The Characteristics of Radiographic Film.

2.1. The concept of image density as log 10 incident light intensity/transmitted light intensity.

2.2. The characteristic curve of a "screen" and "non-screen" radiographic film; film speed expressed as $\frac{1}{E}$ when E = exposure in rontgens; film speed in relation to image density; image contrast in relation to image density; density limitations in industrial radiographs.

2.3. Conventional "negative" presentation of a radiograph and its bearing on radiographic interpretation.

2.4. Use of radiographic film: cassettes, envelope-wrapped, "roll pack".

3. Processing Radiographic Film.

3.1. The chemistry of photographic development: developing agents and their characteristics; the formation of KBr during development; the influence of time, temperature, and solution agitation on development; the function of the alkali, restrainer, and preservative in a developing solution. (This Section can be related to or included in Part 5.3.2).

3.2. Composition and use of developer replenishers.

3.3. Methods and need for the monitoring of developer activity; pH checks; use of pre-exposed film strips.

3.4. Chemistry and function of the stop bath.

3.5. Chemistry and function of fixation: types of fixing solution.

3.6. Washing and drying radiographic film.

3.7. Automatic and manual processing methods: the need for consistency and cleanness in processing; evidence of spurious indications due to careless film handling and processing; darkroom layout; safelights: spectral transmission, brightness.

4. Radiographic Intensifying Screens.

5.1. The function of intensifying screens. Types of intensifying screens.

5.2. Fluorescent salt screens: operating principles, construction, method of use, applications.

5.3. Characteristics of fluorescent salt screens: intensification factors, variation of intensification factor with radiation energy; graininess.

5.4. Metal foil screens: operating principles, construction, foil type and thickness, method of use, intensification factors, variation of intensification factor with screen thickness and radiation energy. Filtration effect of front screen.

5.5. The care of intensifying screens in use and storage.

5. Other Recording Media.

6.1. Paper-based emulsions: "x-ray" paper, bromide printing paper, photo-stabilisation paper. Construction of paper-based recording media.

6.2. Method of use of paper-based emulsions. Avoidance of lateral transposition of image.

6.3. Processing paper-based emulsions: "x-ray" paper, bromide paper, photo-stabilisation paper.

6.4. Characteristics of paper-based emulsions: density range, inherent contrast, speed, graininess of image due to use of salt intensifying screen.

6.5. Xero-radiography: construction of xero-radiographic plates, charging methods, exposure techniques, "development", image formation, image recording by transfer, removal of latent image.

6.6. Advantages of xero-radiography, re-usable plates, care of plates.

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PART 2

THE RADIATIONS USED IN INDUSTRIAL RADIOGRAPHY

(Note: This section concentrates solely on x- and gamma-radiation and makes no reference to other radiations such as neutrons which are not in common routine use in industrial radiography).

1. Nature of the Radiations.

1.1. The electro-magnetic spectrum: x- and gamma-radiation band commencing at about 2Å: identical nature of x- and gamma-radiation; x-rays generated by deceleration of electrons; gamma-rays emitted spontaneously by radioactive atoms; terminology (x- and gamma-) to designate origins, not nature; relationship $v = c/\lambda$.

2. The Generation of X-Rays.

2.1. Construction of an x-ray tube: glass envelope; anode, target, focal spot, significance of line focus; cathode, filament, focussing cup.

2.2. Method of functioning: provision, application and control of high tension; energy conversion at focal spot, $eV = hv$; variation of intensity, "heel" effect; continuous spectrum; influence of HT waveform on mean energy; influence of glass envelope on beam quality; control of tube current.

2.3. Types of x-ray sets: classification in terms of kV range, portable equipment, static equipment, bi-polar, ring radiation, rod anode, micro-focus; tube head mountings, need for flexibility with rigidity; control panels.

3. The Generation of Gamma-Radiation.

3.1. Radioactivity: types of radiation, criteria for suitability as a radiographic source; the curie, specific activity, radioactive decay and half life; line spectra; artificial and naturally-occurring sources; source form and dimensions; commonly available gamma-ray sources.

4. Properties of X- and Gamma-radiation.

4.1. Rectilinear propagation: formation of umbra and penumbra; inverse square law.

4.2. Refraction and reflection: reference to Bragg's Law and its bearing on diffraction mottle in radiographs.

4.3. Absorption: linear and mass absorption coefficients; absorption of mono-chromatic and mixed beams; scattering and photo-electric effects; luminescent properties, fluorescence, phosphorescence in relation to salt intensifying screens; ionisation of gases in relation to radiation detection and measurement.

4.4. Photographic effect: Gurney & Mott theory of latent image formation. (See also Section 1 "The Nature of an Industrial Radiograph".).

4.5. Physiological effects and their relationship to radiation safety. (See also Section 3.1.1.).

5. The Concept of Radiation Quality.

5.1. The need for the quantification of beam energy: reproducibility of exposure conditions, variability of radiation quality from x-ray tubes as compared with gamma-ray sources.

5.2. Methods of quantification: disadvantages in the use of wavelength, applied kilovoltage; the half-value layer concept.

6. The Detection and Measurement of X- and Gamma-radiation.

6.1. The range of measurements required: output performance of x-ray sets and gamma-ray sources; leakage of radiation in relation to personnel protection.

6.2. Units of measurement: rontgen, rad, rem.

6.3. Measuring equipment: principles of operation and methods of use of ionisation chamber, condenser chamber, geiger counters, quartz-fibre electroscopes; energy dependent characteristics of detecting and measuring equipment; influence of "broad beam" conditions on measured intensity; calibration of equipment.

6.4. The film-badge: basic principles and manner of use of the radiation film badge.

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PART 3.

THE INSTALLATION AND SAFE USE OF RADIOGRAPHIC EQUIPMENT.

1. Safety Regulations.

1.1. Regulations: international regulations, recommendations, codes of practice; maximum permissible dose rates for radiation workers and others; minimum age for radiation workers; cumulative dose formula 5 (N-18) rem.; medical requirements for radiation workers; national regulations governing the installation and use of sources of ionising radiation.

1.2. The storage and transport of gamma-ray sources; national and international regulations.

1.3. The need for staff training in the recognition and control of radiation hazards; the provision of and adherence to correct working procedures.

1.4. The provision of a film badge and radiation monitoring service; the maintenance of radiation dosage records.

2. Radiographic Laboratories.

2.1. Selection of site: ground level site preferred; convenience of access with respect to work source; consideration of adjacent occupied areas.

2.2. Determination of shielding thickness for a permanent laboratory. The following points must be taken into consideration: operative maximum leakage dose-rates (0.5, 0.75, 2.5 mr/hour); radiation output at maximum kV and mA (x-ray sets) and maximum source strength and energy (gamma-ray sources) measured at 1 m.; relate maximum radiation output to required leakage dose-rate to obtain attenuation factor; use of published attenuation curves to determine required thickness of lead for "broad beam" conditions; use of lead equivalents for other shielding materials; incorporation of existing walls as whole or part of shielding.

2.3. Construction details: continuity of shielding between abutting lead panels and at base of shielded walls and floor; avoidance of "straight through" radiation leakage paths at cable and water pipe entry points, door shielding, wall shielding overlap; avoidance of overhead leakage of radiation from open-topped shielded cubicles.

2.4. Special safety features: provision of door interlock switches; provision of audible and/or visual warning devices; provision of "panic" switch in exposure room; special considerations relating to the use of gamma-ray sources; radiation monitor survey of completed installation.

3. Site Radiography.

3.1. Provision of safe working conditions. The following points must be taken into consideration: determination of the maximum output of the source (x-ray set, gamma-ray source) to be used; use of distance to reduce radiation intensity; erection of barriers and warning signs; monitor survey around site perimeter; surveillance of site during exposures

4. The Use of Gamma-ray Sources.

5.1. Containers for gamma-ray sources; source handling systems, mechanical, pneumatic; interlocks; setting-up procedure with dummy source; periodic check for leakage of contents from source capsule.

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PART 4.

THE PREPARATION AND APPLICATION OF RADIOGRAPHIC TECHNIQUES

(Note: the term "radiographic technique" is used to describe a method for the radiographic examination of a specific design of casting, weldment, or other specimen. A radiographic technique will consist of one or more exposures, and gives the required degree of coverage of the specimen concerned.).

1. Preliminary Considerations.

1.1. Inspectional requirements: extent of coverage, location of any areas of special importance within the specimen, anticipated location and nature of defects, economic requirements, i.e., avoidance of an excessive number of exposures.

1.2. Radiographic requirements: sensitivity required, standard of image sharpness, ease of application in a routine situation.

1.3. Breakdown of problems into three main areas: selection of exposure conditions; number of exposures required for complete coverage; selection of aspect for each exposure.

2. Selection of Exposure Conditions.

2.1. Exposure calculations: variation of exposure time with tube current (x-rays), source strength (gamma-ray sources), film-focus distance.

2.2. Construction and use of an exposure chart: limiting parameters including type of equipment, film type, use of screens, filters, film-focus distance, material, image density, development conditions.

2.3. Use of an exposure chart in combination with film characteristic curve for multi-section specimens.

2.4. Radiographic equivalence factors.

2.5. Trial and error methods: standardisation of certain variables, e.g., development conditions; considerations governing initial selection of film type, intensifying screens, exposure geometry, tube current; trial exposures varying kV and time independently; final selection of kV and time.

3. Number of Exposures and Selection of Aspect.

3.1. Factors influencing the number of exposures required per specimen:

3.1.1. limited density range of the radiograph imposes restrictions on the specimen thickness range that can be accommodated in a single exposure, e.g., 3:1 for light metals, 2:1 for dense metals.

3.1.2. the configuration of a complex specimen introduces, in any one exposure, unsuitable aspects in some areas and creates a thickness range exceeding those quoted in 3.1.1. above

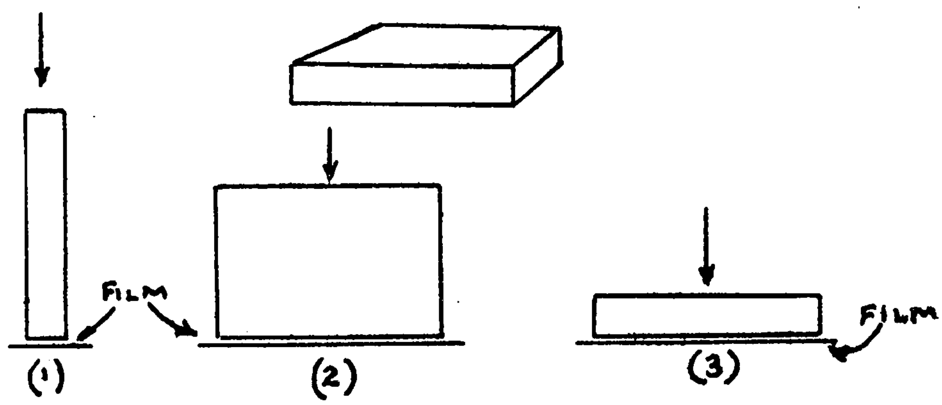
3.1.3. specimens of mixed composition, e.g., metal and plastic, may require separate exposures for each material.

4. The Radiographic Examination of Castings.

4.1. In teaching this section of the syllabus the aim should be to persuade the student to visualise the casting as a collection of "basic shapes" rather than one complete entity. The "basic shapes" include (a) flat plates, (b) L-sections, (c) T-sections, (d) H-sections, (e) hollow box (□) sections, (f) solid cylinders, and (g) hollow cylinders. If the requirements for covering each of these shapes are considered, a technique can then be built up in a logical manner for any casting consisting of one or more of these shapes. In practice care has to be taken to ensure that this fundamental approach does not exclude consideration of other over-riding requirements, e.g. the need to include a particular aspect to detect a defect that aligns itself in a particular plane, or the possibility of duplication of coverage of certain areas. Provided that due attention is paid to these other considerations, the "basic shape" approach induces a logical and thorough approach to technique compilation.

4.2. The treatment of basic shapes:

4.2.1. Flat Plate.

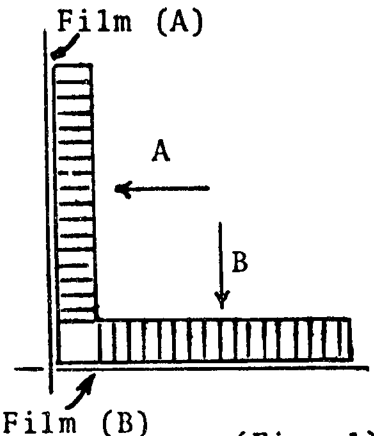


At least three approaches are available. Of those shown above N°3 is preferred for the following reasons:

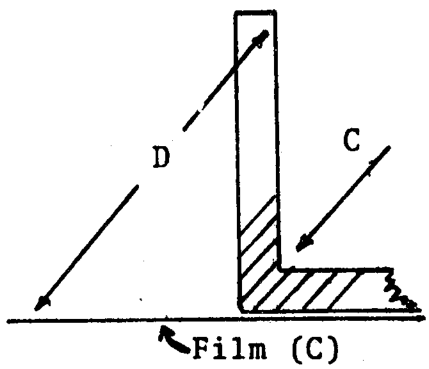
(a) the shorter path length for the radiation through the specimen ensures the detection of finer detail

(b) the more natural projection of this aspect avoids excessive super-imposition of detail.

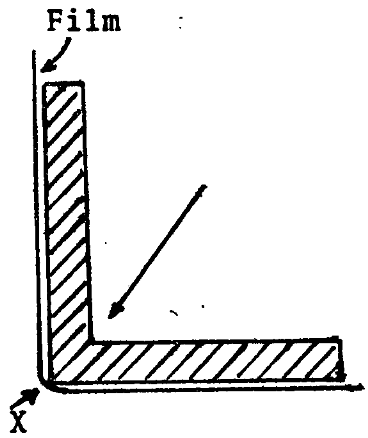
4.2.2. <u>L-sections.</u>



(Fig. 1)



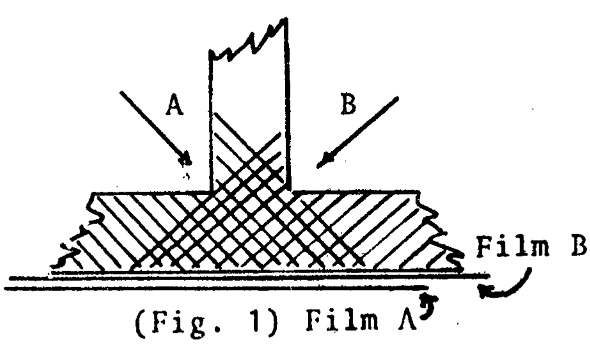
(Fig. 2)



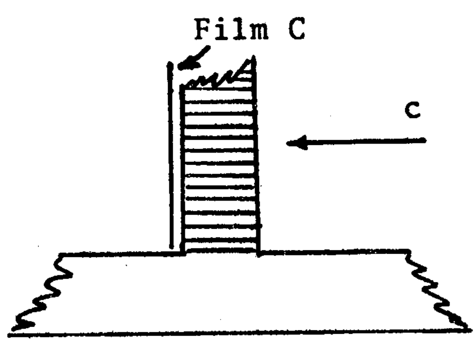
(Fig. 3)

Treat as two flat plates. In Fig. 1 exposures A and B are made to cover the upright and horizontal areas respectively. Neither A nor B reveals the junction area (unshaded). A third exposure (C in Fig. 2) is required for this area. Exposure C in Fig. 2 may sometimes give an acceptable illustration of the entire piece provided that the image unsharpness induced by distance D is within acceptable limits. An alternative to C, Fig. 2, is shown in Fig. 3. However, this latter approach creates the possibility of severe pressure marking in the radiograph at point x if the film is forced around a sharp radius. This approach is not suitable for exposures requiring the use of intensifying screens.

4.2.3. <u>T and H-sections.</u>

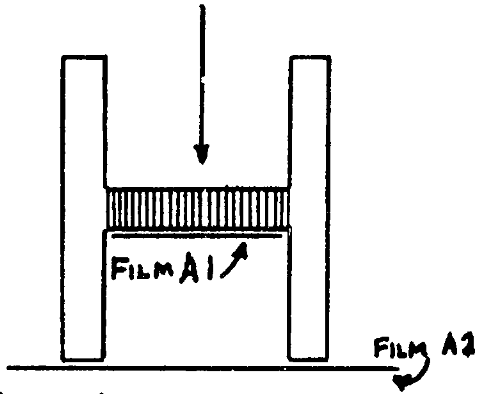


(Fig. 1)

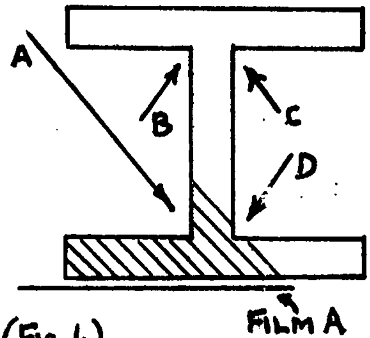


(Fig. 2)

The "flat plate" approach is adopted. Exposure A (Fig. 1) covers part of the horizontal area and its junction with the upright member. A similar exposure (B Fig. 1) completes the coverage of these areas. A third exposure (C Fig. 2) is used to cover the vertical member.



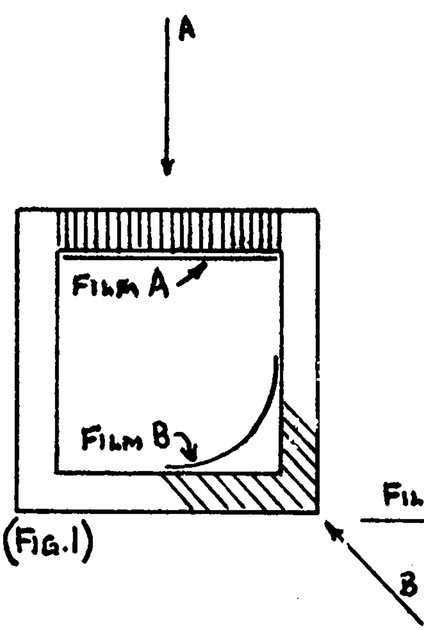
(FIG. 3)



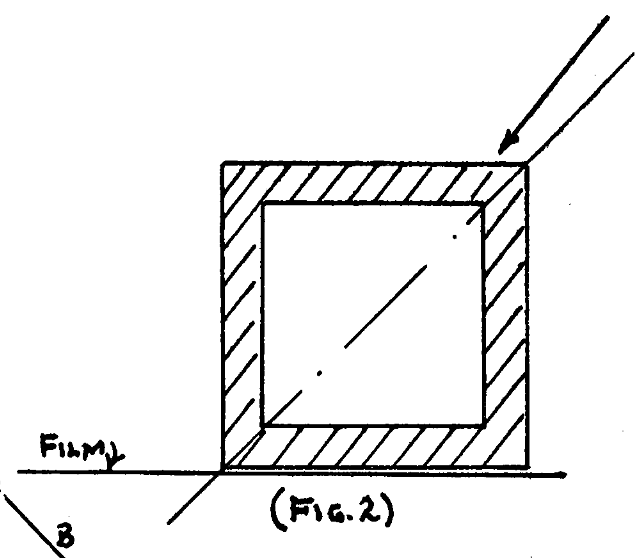
(FIG. 4)

The central web of the H-section is covered by the "flat plate" approach (Fig. 3). If it is difficult to position the film in the A1 position, position A2 can be used as an alternative. In the latter instance the film-focus distance must be increased to off-set the unsharpness arising from the object-film distance introduced by the A2 film position. The remainder of the piece is covered by the exposure A in Fig. 4 and the three similar exposures B, C, and D.

4.2.4. <u>Hollow Box Sections.</u>



(FIG.1)

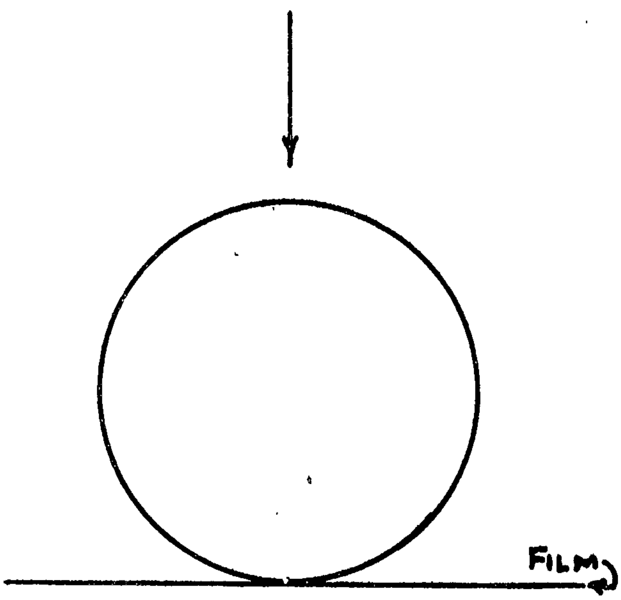


(FIG.2)

Fig. 1 illustrates an approach that is suitable for open-ended box sections free from internal details that might prevent the positioning of the film within the box section. Exposure A, Fig. 1 may be used to cover the side. Exposure B, Fig. 1 is intended to cover the junction area between two walls. In some circumstances Exposure B may also provide an adequate illustration of the adjacent walls.

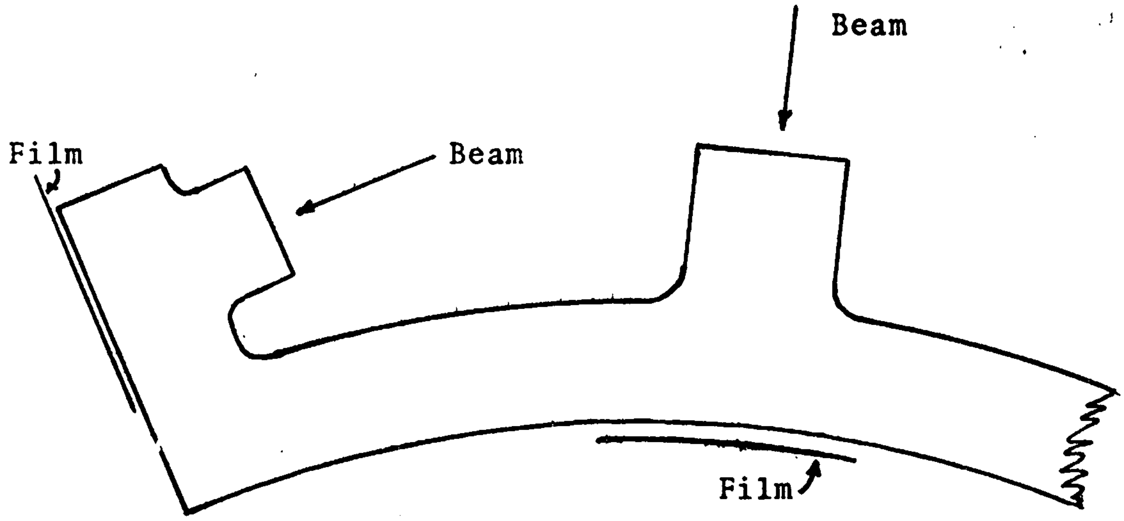
Fig. 2 illustrates an approach for use when the film cannot be positioned inside the box section. This approach is based on the "double-wall, double-image" principle (see 4.2.6) and requires two exposures for complete coverage. Note that the beam axis in both exposures is slightly off-set from the diagonal joining opposite corners in order to reduce the thickness changes.

4.2.5. Solid Cylinders.



(FIG. 1)

Fig. 1 shows a method for the radiography of a simple cylinder without any associated attachments. One exposure as shown is usually sufficient for cylinders up to 25 mm. in diameters. Larger diameters will require two such exposures, one at a lower kilovoltage for the thinner peripheral areas and a second in the same direction at a higher kilovoltage for the central thicker areas. (See also "Contrast Reduction Methods"). In casting radiography solid cylinders are often encountered as bosses, etc., and in such instances it may be possible to utilise an exposure aligned with the longitudinal axis of the boss. (See Fig. 2). The advantages of this approach are that it presents a uniform thickness and may align the beam with the main axis of any shrinkage piping that might develop in the boss.



(Fig. 2)

4.2.6. Hollow Cylinders.

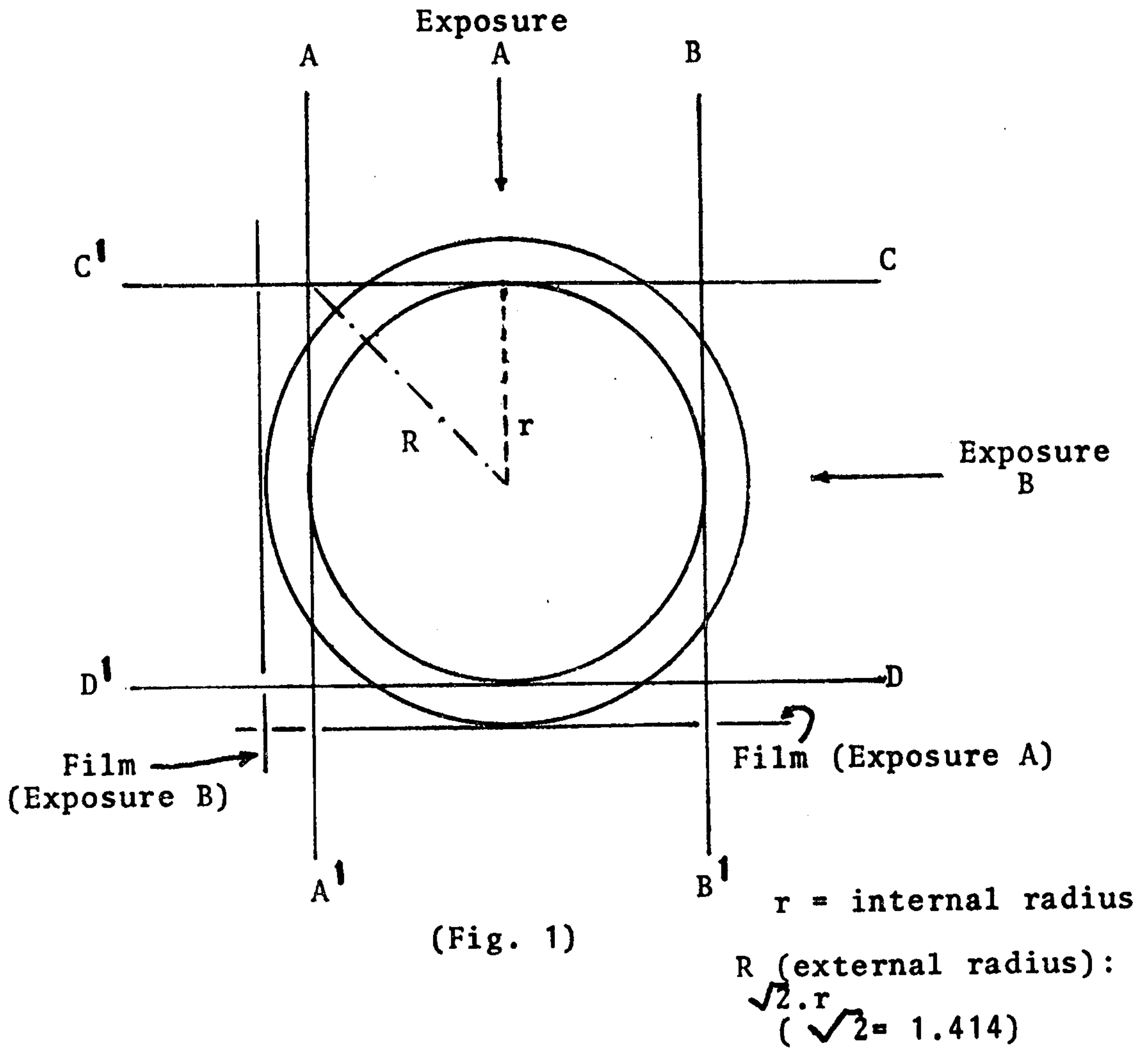
4.2.6.1. There are two methods by which hollow cylinders may be examined:

(a) "double-wall, double-image",

(b) "single-wall, single-image".

"Double-wall, double-image" methods are suitable for use when it is not possible to position the film or the radiation source inside the cylinder. They are, in general, more suited to the examination of hollow cylinders of relatively small outside diameter (e.g. 150 mm. max.). Their application to cylinders of larger diameter is not usually economically viable because of the long exposure times involved with such specimens. Single-wall methods can be applied only to open-ended cylinders.

4.2.6.2. <u>Double-wall, double-image.</u>



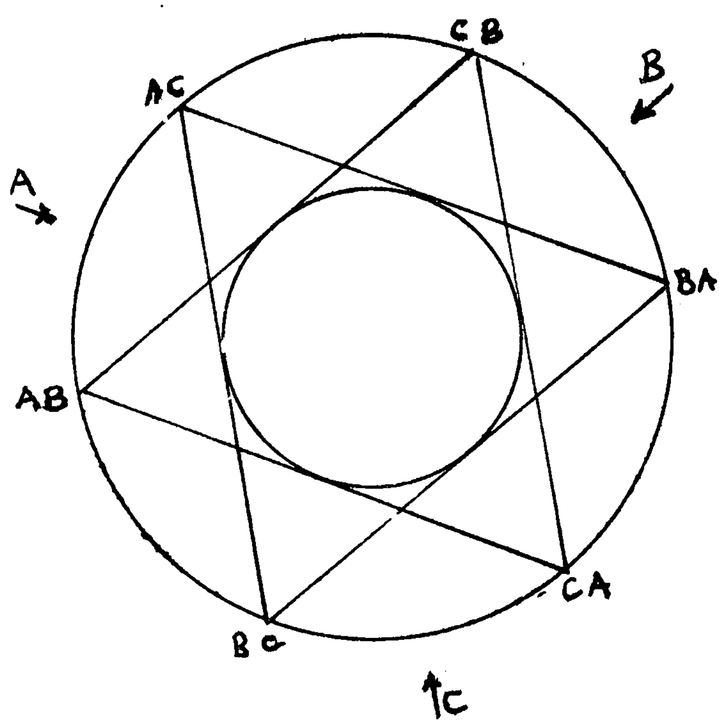
(Fig. 1)

Exposure A (Fig. 1) covers those segments of the wall between parallel lines AA'/BB'. A second exposure in the direction of arrow B covers the remaining segments between parallel lines CC'/DD'. It can be seen from Fig. 2 that provided that R does not exceed 1.4 x r, two exposures mutually at 90° separation will give complete coverage of the walls of the cylinder.

When R exceeds 1.4 x r (Fig. 1) the number of exposures requited for complete coverage of a hollow cylinder by the "double-wall, double-image" method is as follows:

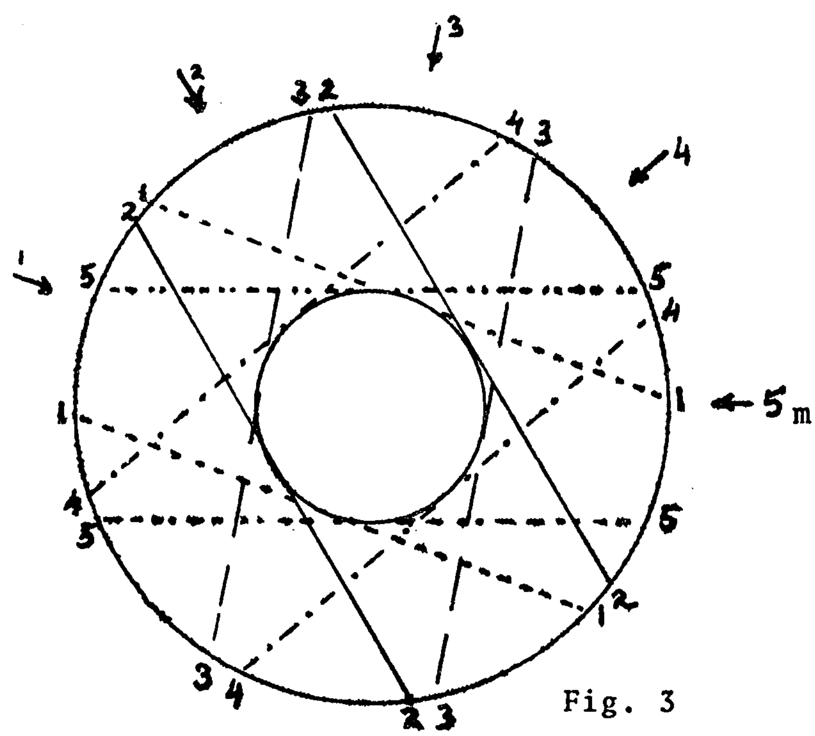
(a) when R/r is not greater than 2, use 3 exposures at 120° around the circumference, (see Fig. 2),

(b) when R/r is greater than 2, use 5 exposures at 40° separation within one half of the circumference, (see Fig. 3).



Three exposures (arrows A,B,C,) at 120°separation. Coverage of each exposure indicated by lettered pairs of parallel lines.

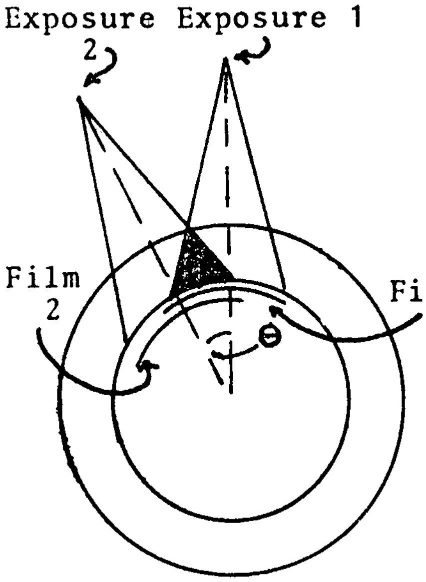
Fig. 2



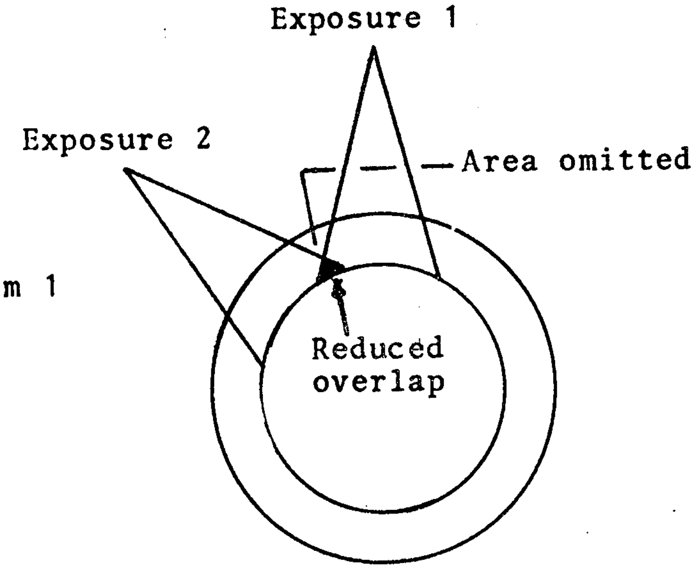
Five exposures (arrows 1 to 5) at 40° separation. Coverage of individual exposures indicated by pairs of numbered parallel lines.

Fig. 3

4.2.6.3. Single wall-single image.



(Fig. 1)

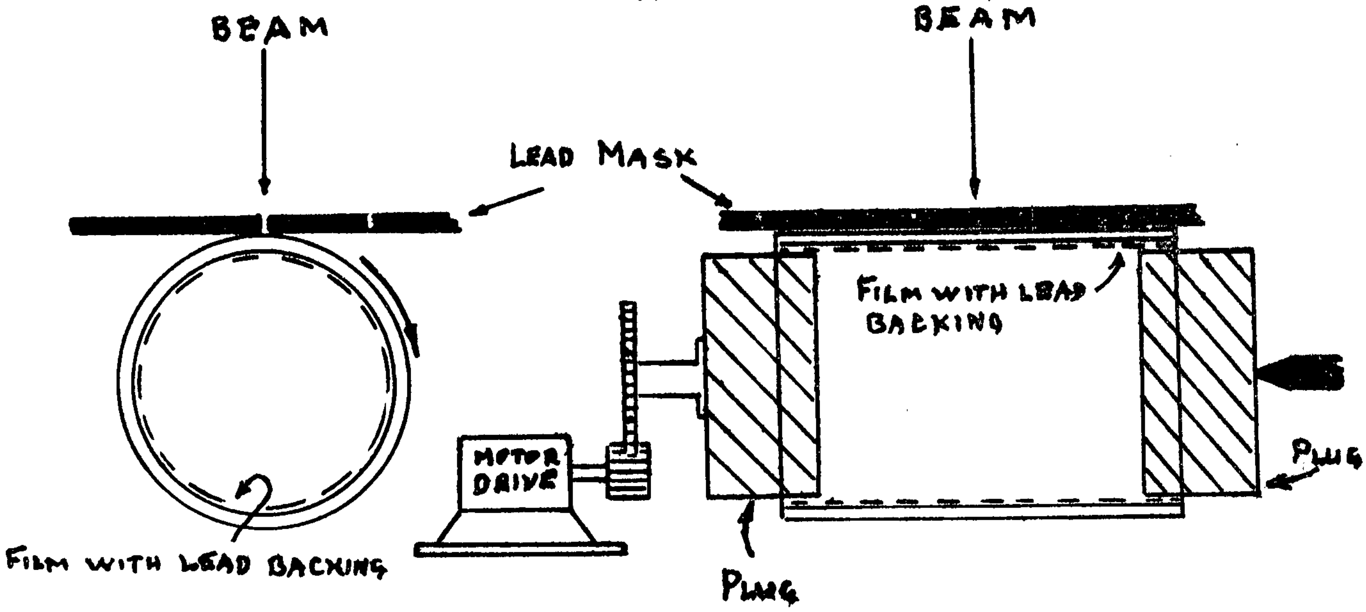


(Fig. 2)

Fig. 1 illustrates a method in which the radiation source is located outside the cylinder and the film is placed in contact with the inside surface of the cylinder wall. The extent of coverage around the cylinder wall given in a single film should be such that the radiation path length through the cylinder wall at film extremities is not increased by more than 10% of the nominal wall thickness. The angular separation between exposures ($\angle\theta$, Fig. 1) must be selected to ensure that there is continuous overlap of coverage through the wall thickness between adjacent films. A marker should be placed on the outer surface to confirm that overlap has been obtained. Fig. 2 shows lack of overlap arises when an excessive angular separation is used.

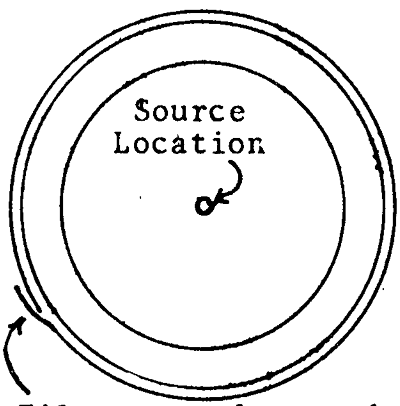
4.2.6.4. "Rotation" method, single-wall, single-image.

This method is suitable for plain, open-ended cylinders free from upstanding internal or external surface features such as bosses, ribs, etc., and having a wall

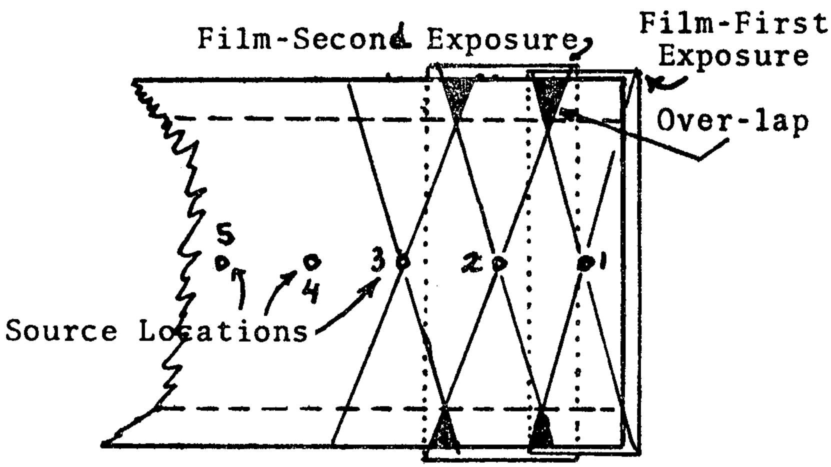


thickness up to about 6 mm. max. The beam of radiation is centred on a narrow slit (about 2-3 mm. in width) in a sheet of lead of sufficient thickness to absorb completely the beam of radiation. The cylinder, with film and lead-backing inserted, is positioned with its centre in the plane of the slit and with its outer surface just clearing the lead sheet. The cylinder is rotated under the slit during the exposure of the film. The minimum speed of rotation of the cylinder should be such that the time taken for a point on its outer surface to move past the slit is equal to the exposure time required to produce a conventional radiograph of the cylinder wall. On this basis a single rotation will yield a radiograph of the entire cylinder wall. Faster speeds of rotation will require more than one rotation of the cylinder to produce a satisfactorily exposed radiograph, the number of rotations required being based on the ratio of the actual speed of rotation to the basic speed of rotation. (High rotational speeds should be avoided in order to eliminate a stroboscopic effect in the radiographic image arising from the pulsed output of certain types of x-ray sets.) Information on the parameters controlling the image quality of rotation radiographs are given in Brit. J. of NDT Vol. 19 N°3, pages 122-125, May 1977).

4.2.6.5. <u>Film outside, source inside, cylinder, single-wall, single-image.</u>



Film wrapped around outer surface. Note over-lap at ends.



This method is suitable for use with gamma-ray sources and "ring radiation" x-ray tubes. Using such sources, which are located at the geometric centre of the cylinder, the wall of the cylinder can be completely covered in a single exposure. Length-wise coverage will require the use of a series of such exposures along the length of the cylinder. Overlap between separate "bands" will be based on the "increased path length" concept referred to in 4.2.6.3, together with the use of verification markers.

Rod anode x-ray tubes can be employed for this method, but in this instance circumferential coverage will be obtained by the use of a series of separate, overlapping exposures.

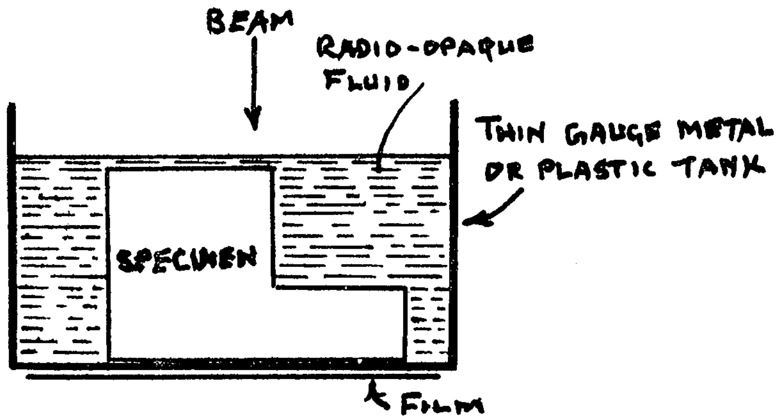
5. Contrast Control Methods.

5.1. Contrast Reduction.

5.1.1. Contrast reduction methods are for use with specimens that, because of a very wide thickness range, create a "high contrast" image, i.e., the thickest and thinnest areas cannot be accommodated within the normal acceptable image density range of a single radiograph. Contrast reduction techniques overcome this problem by the use of a greatly increased radiation energy, sometimes in combination with an artificial build-up of the thinner sections. It follows, therefore, that such methods will always result in a degradation of image quality in the thinner areas of the specimen. The loss of quality must be assessed in the light of the relevant inspectional requirements before such methods are to be used in any particular application.

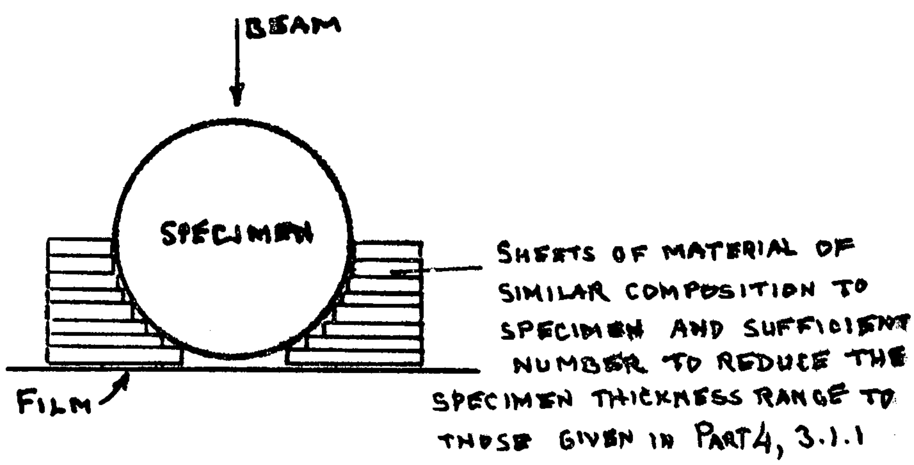
5.1.2. Immersion Methods.

These are suitable for small specimens that can be immersed conveniently in a tank of radio-opaque fluid that just covers the thickest section.



Solutions used should have an absorption coefficient similar to that of the specimen and may be carbon tetrachloride (for light metals) and an aqueous solution of lead nitrate (for dense metals). The strength of the latter solution should be adjusted by experiment to suit the specimen. NOTE: check for compatibility between specimen and solution. Thoroughly wash and dry specimens after immersion in aqueous solutions. LEAD NITRATE IS VERY TOXIC: RUBBER GLOVES MUST BE WORN WHEN IT IS HANDLED.

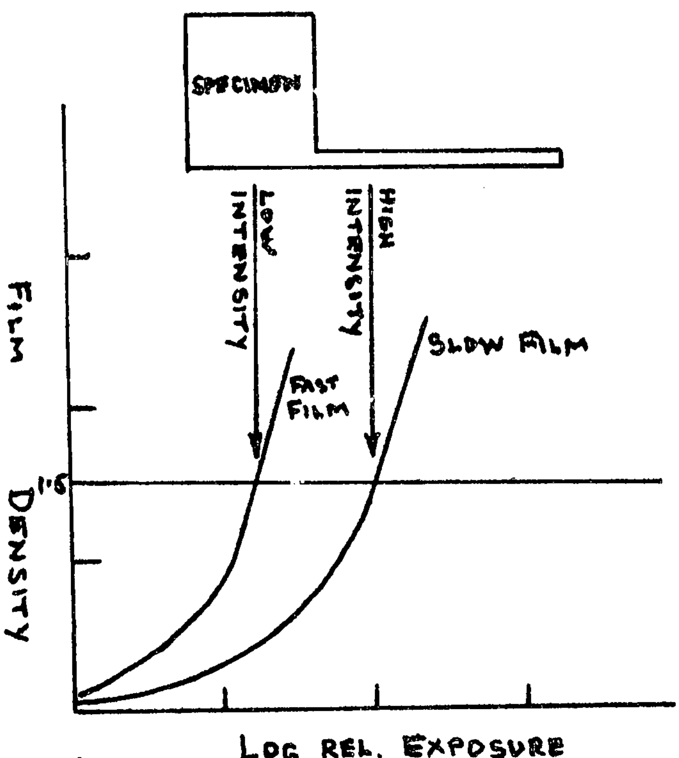
5.1.3. Build-up Methods.



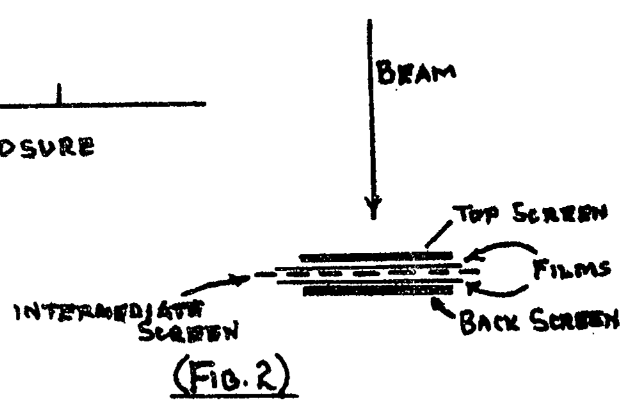
In a "build-up" method, additional material is added to the thinner section in order to reduce the thickness range of the specimen. The added material is usually in the form of sheet material having absorption characteristics similar to those of the material of the specimen; alternatively a lesser thickness of more dense material can be employed. "Build-up" methods tend to create a shadow pattern that is superimposed on the main image in the radiograph. This may interfere with the interpretation of the main image details.

5.1.4. Double Film Method.

This method is based on the simultaneous exposure of a slow and a fast radiographic film in the same cassette. The exposure is made at a kilovoltage suited to the thickest section in the specimen. (No additional material is placed on the thinner sections). The exposure is adjusted by experiment to yield a satisfactory image density for the thin sections on the slower film, while the thickest sections are recorded on the faster film. If the exposure requires the use of lead screens, an intermediate screen should be placed between the two films. This screen is not mounted on a card support. (See Fig. 2).



(FIG.1)



(FIG.2)

5.1.5. Increased Energy Method.

An increase in radiation energy, e.g. the use of Iridium 192 in place of 200 kV x-rays, will give a considerable reduction in image contrast. No exact guidance can be given. Individual cases should be investigated by experiment.

6. The Radiography of Weldments.

6.1. General Considerations.

(a) In the examination of a weldment, radiography is restircted to the weld run and the immediately adjacent heat-affected zones. The radiographic examination is not concerned with the body of the weldment.

(b) The radiographic examination of welds in certain fields of engineering, e.g., pipe-lines, pressure vessels, boilers, nuclear installations, is governed by well-established codes of practice such as those issued by ASME. These codes of practice may stipulate the techniques (aspects, number of shots) and exposure conditions that are to be used in specific instances.

6.2. Basic Principles.

(a) Weld defects fall into two distinct categories (1) "volume" defects such as porosity, discrete gas cavities, slag inclusions and (2) "laminar" defects such as cracks, lack of side and inter-run fusion.

(b) "Volume" defects, because of their geometric form, are capable of detection from most angles of view. "Laminar" defects, because they lie in a single plane, are detectable only when the beam angle coincides with a major plane of the defect; in addition, width and length of the image of a laminar defect must exceed the total unsharpness of the radiographic process if the defect is to be detected.

(c) Surface features such as under-cutting, shrinkage grooves, spatter, grinding and chipping marks, and the surface condition of the weld bend in the instance of undressed welds tend to be a greater hazard in the interpretation of weld radiographs than in the interpretation of radiographs of castings.

6.3. Practical Techniques.

6.3.1. Butt-welds in plate.

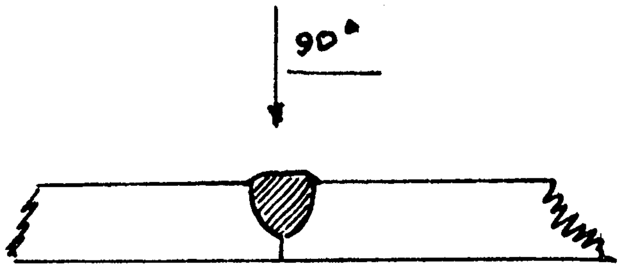


Fig. 1. U-preparation.

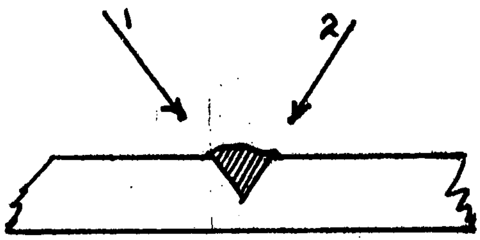


Fig. 2.Vee-preparation.

Depending upon the edge-preparation of the plate a single exposure at 90° (Fig. 1. U-preparation) or two angled exposures (Fig. 2Vee-preparation) may be required. In the latter instance, economic considerations may force the adoption of a single 90° shot.

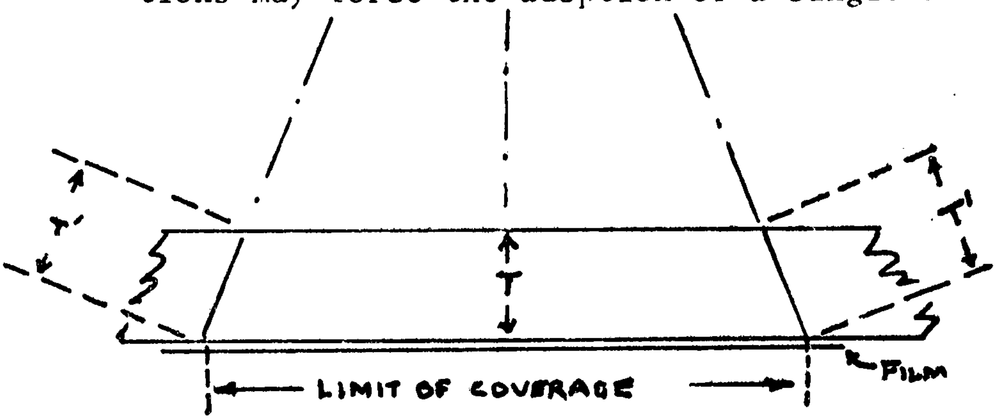


Fig. 3. Limit of Coverage.

The length of weld run to be covered in a single radiograph should be such that the radiation path length through the weld at the film extremities is not more than 10% greater than the plate thickness, i.e., as shown in Fig. 3, T' should not exceed 1.1T, where T is the plate thickness and T' the increased path length.

6.4. <u>Circumferential Butt-welds in Pipe.</u>

6.4.1. Double-wall, double image techniques are based on the principles described for hollow cylinders in Part 4, 4.2.6.2. The following modification should be introduced for the radiographic examination of circumferential butt-welds in the pipe. (See Fig. 4). The beam is off-set to separate in the radiograph the images of the upper and lower segments of the weld recorded in a single film.

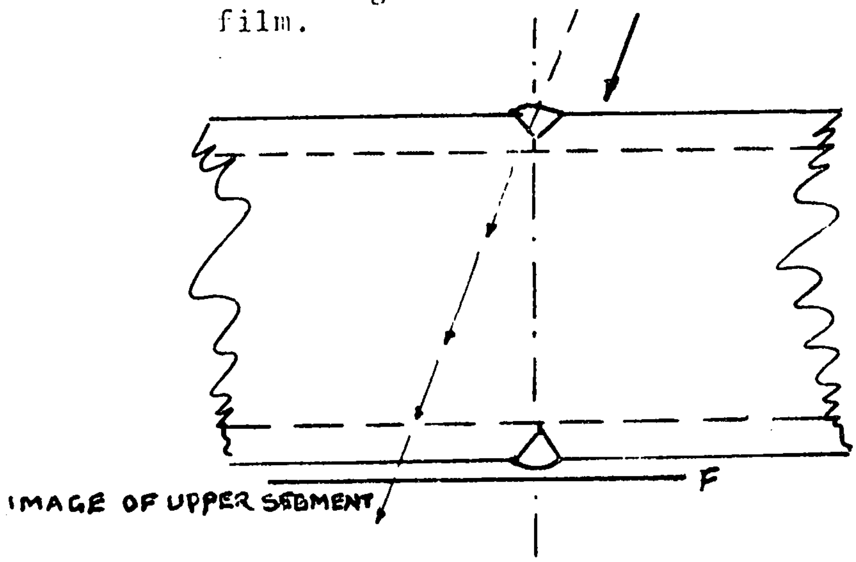
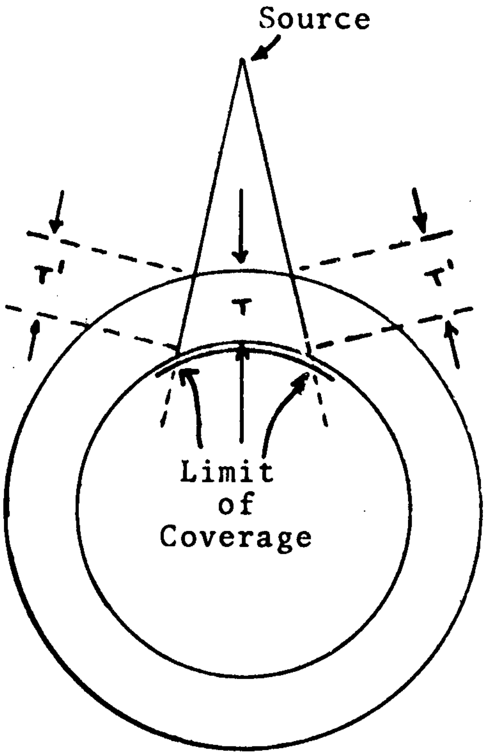
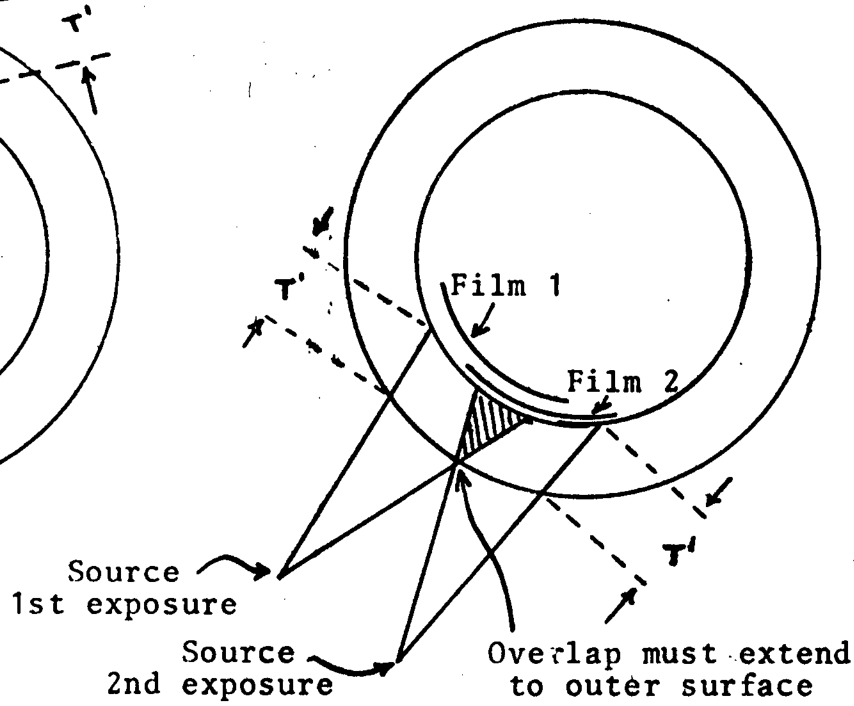


Fig. 4. Off-set beam method.

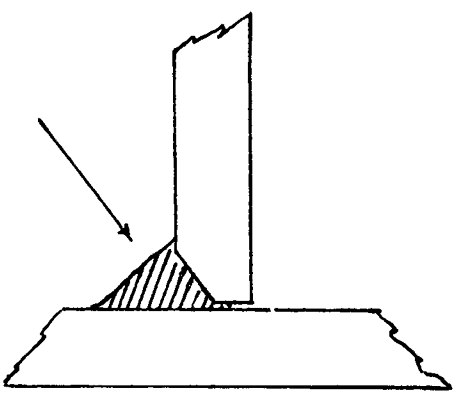
6.4.2. Single-wall, single-image techniques similar to those described in Part 4, 4.2.6.3. and 4.2.6.5. can be employed when the interior of the pipe is accessible and, in the instance of 4.2.6.5, when the pipe dimensions do not introduce the possibility of excessive image unsharpness due to short source-film distances.

Techniques based on that described in Part 4, 4.2.6.3. are affected by a marked increase in the thickness to be penetrated at the film extremities as the curvature of the specimen increasingly aligns itself with the beam path ((see Fig. 5). The restriction on the length of weld covered in a single exposure is governed by the principle mentioned in 6.3.1. above. Figs. 4a and 4b show the application of this principle in the examination of a circumferential butt-weld

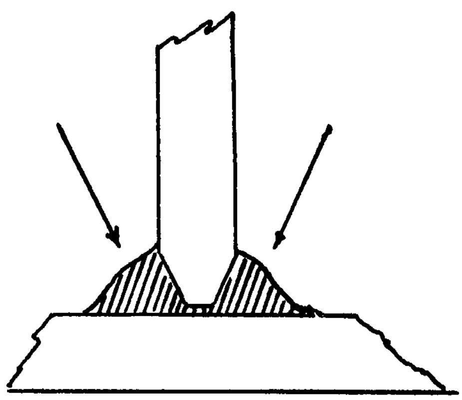




6.5. <u>Fillet Welds, Plate-to-Plate.</u>



(Fig. 5)

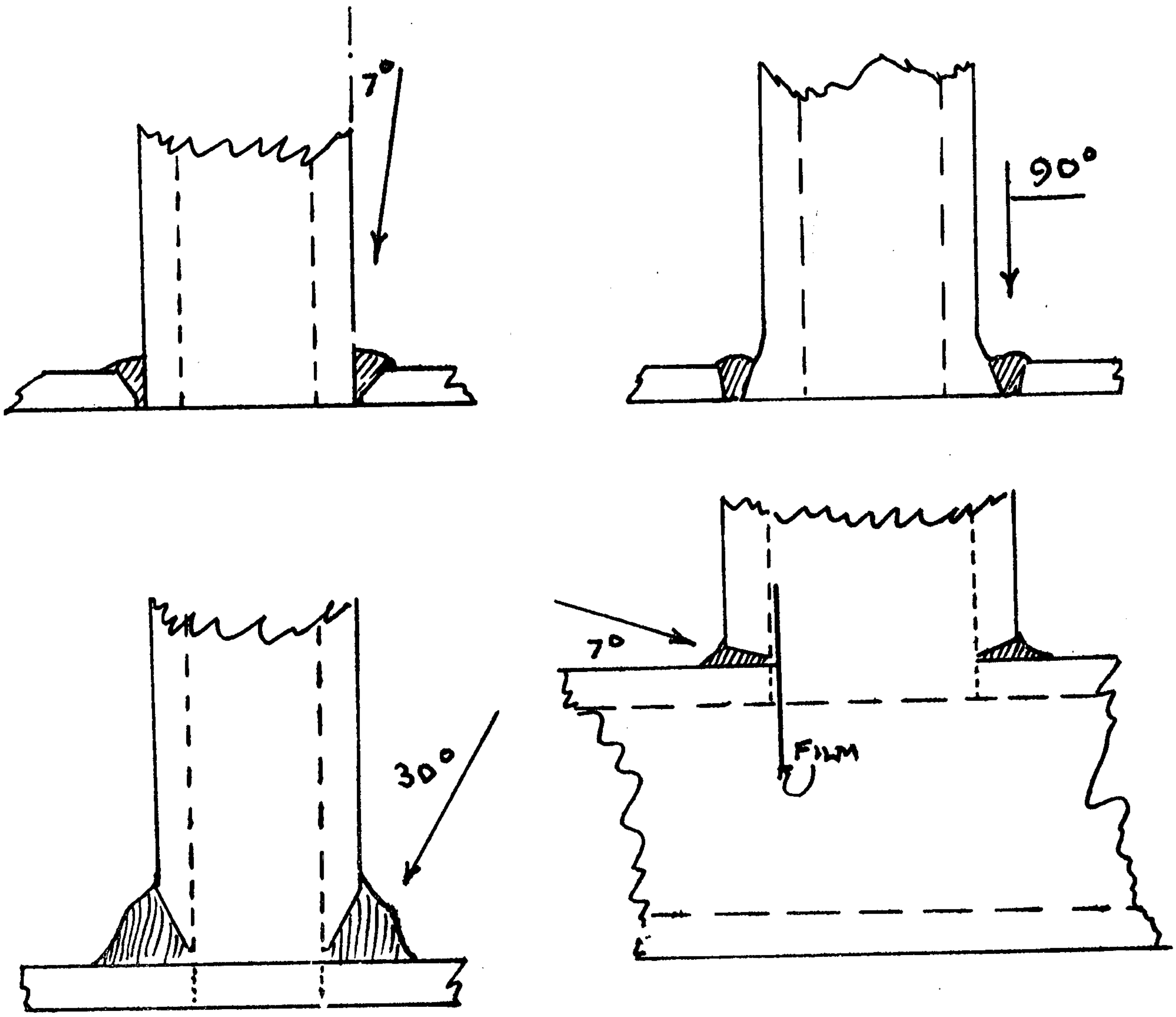


(Fig. 5a.)

The direction of the beam of radiation is aligned to coincide with the plane of the edge preparation (see Figs. 5 and 5a).

6.6. Fillet Welds, Nozzles.

The following methods are based on the ASME Boiler and Pressure Vessel Code.



The radiation beam direction is aligned to coincide with the plane of the edge preparation. Circumferential coverage is obtained by adherence to the principles in Part 4, 4.2.6.1. to 4.2.6.3. as appropriate, in conjunction with the guidance given in Part 4, 6.4.2.

6.7. Identification of Radiographs.

Care must be taken to enable all radiographs to be accurately correlated with the areas of the weld run that they illustrate. Identification may be carried out by means of permanent marks (letters or numerals) placed on the weldment, over which are positioned corresponding lead letters or numerals that are reproduced in the radiograph.

Overlapping radiographs bear identical reference letters or numerals in the area of overlap (see Fig. 7). Some

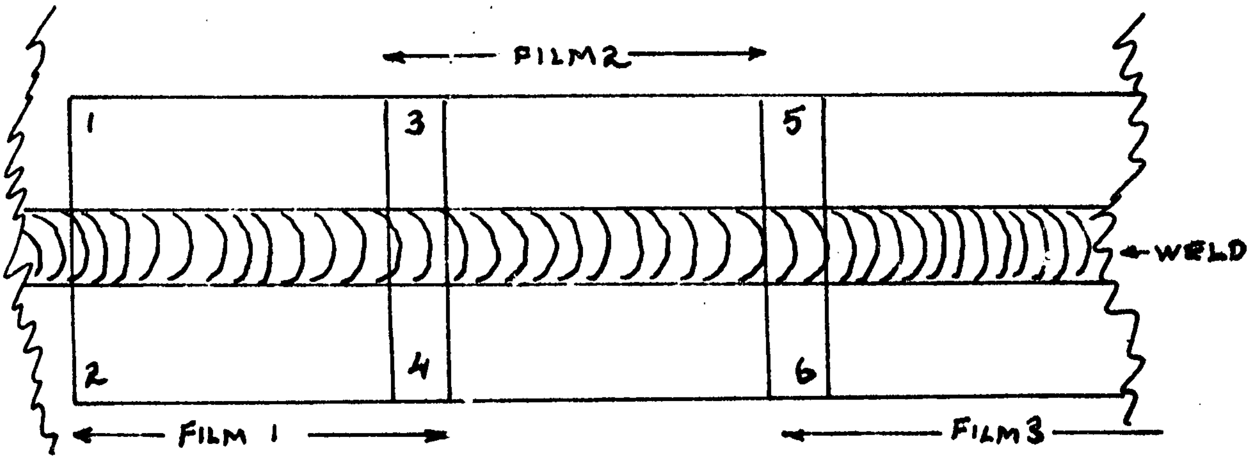


Fig. 7. Identification of Radiographs.

Codes of Practice may stipulate the method of identification to be used.

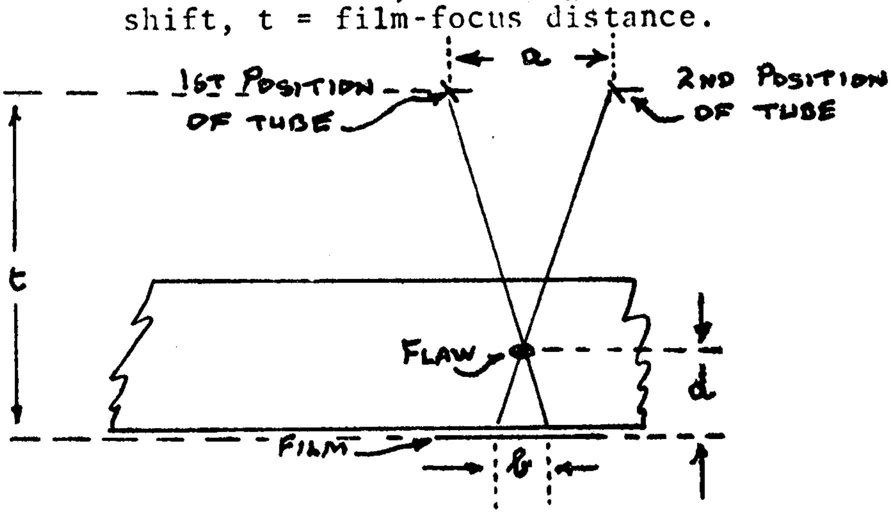
7. Defect Localisation.

7.1. Stereoscopic Methods.

The principles of stereoscopic vision; types and use of stereoscopes; stereoradiographic methods; maintenance of correct perspective when working at FFD's greater than normal reading (viewing) distance.

7.2. Triangulation Methods.

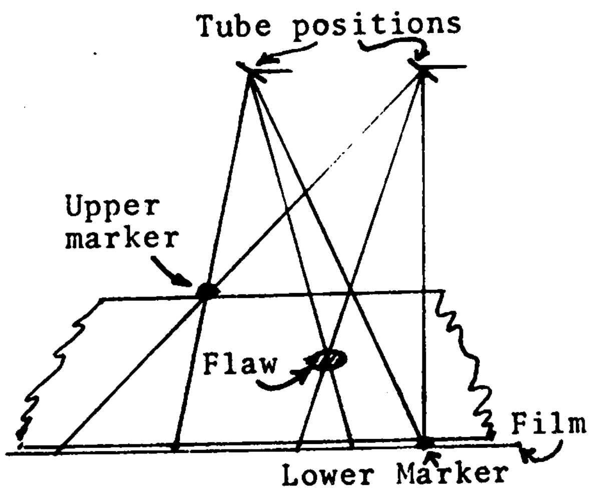
7.2.1. Tube-shift method involving double exposed film using half normal exposure time in each instance. In Fig. 8, a = tube shift, d = height of flaw above film, b = image shift, t = film-focus distance.



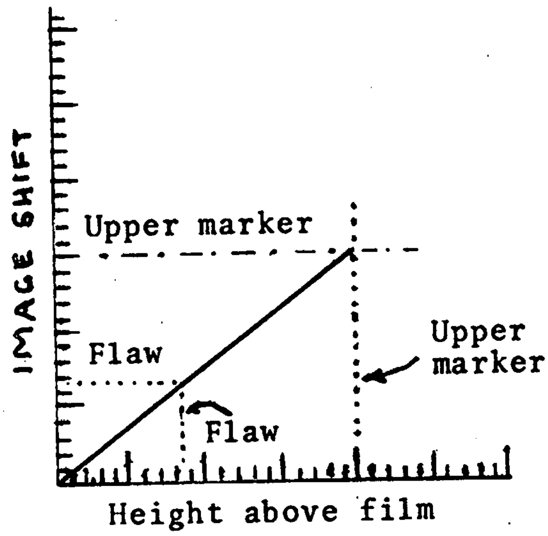
$$d = \frac{bt}{a+b}$$

Fig. 8. Tube-shift Method.

7.2.2. Graphical method.



(Fig. 9)



(Fig. 10)

(a) Place a marker (see Fig. 9) on the upper and lower surfaces of the defective layer. Measure the height above the film of the upper and lower markers. (If the lower surface of the layer is in contact with the film, height of lower marker can be taken as zero).

(b) Make two exposures on one film as in 7.2.1., i.e., with known tube shift between exposures, half exposure time in each instance.

(c) Measure image shift for upper marker, lower marker, and flaw. (If the lower marker and film were in contact, image shift for lower marker will be zero).

(d) Join with a straight line on the graph those points corresponding to "height above film" and "image shift" for each marker. (See Fig. 10).

(e) Read off "height above film" corresponding to measured "image shift" of flaw.

PART 5.

RADIOGRAPHIC QUALITY.

1. The Nature of Radiographic Quality.

1.1. Given that a suitable aspect is employed (see Part 4, 4.1. to 4.2.6.4.), the standard of radiographic quality achieved is controlled by the combined effects of two main factors:

(a) image sharpness, and
(b) image contrast.

1.2. Definition of image sharpness and image contrast; quantification of image sharpness and image contrast.

1.3. Verification of radiographic quality by the use of an image quality indicator (IQI); definition of radiographic sensitivity; types of IQI and their incluence on sensitivity values achieved; relationship between achieved sensitivity and minimum detectable size of defect.

2. Factors Influencing Image Sharpness.

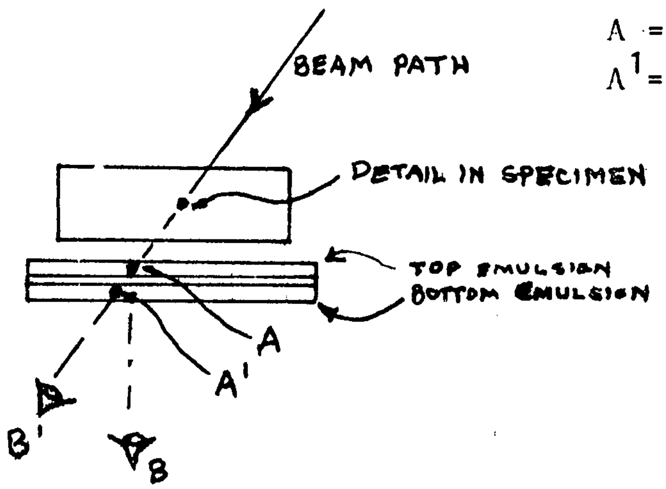
2.1. Geometric factors: the formation of penumbra in shadow projection; 0.25 mm. as an acceptable standard of penumbral width; geometrical relationship between source dimensions, source-object distance, object-film distance; practical implications of object-film distance in relation to specimen thickness and hollow objects examined by the "double-wall, double-image" method; advantages of projection techniques with micro-focus equipment.

2.2. Unsharpness due to movement: avoidance of relative movement of source, film, and specimen during exposure.

2.3. Sources of movement: unstable mounting of radiation source, vibration transmitted from adjacent heavy plant; wind-induced movement of light structures, e.g. aircraft, during site radiography.

2.4. Inherent unsharpness due to film characteristics: emulsion graininess; influence of radiation energy on graininess; influence of parallax effect (double-coated films) on apparent sharpness in oblique aspects.

A = Image, top emulsion
A^1= Image, bottom emulsion

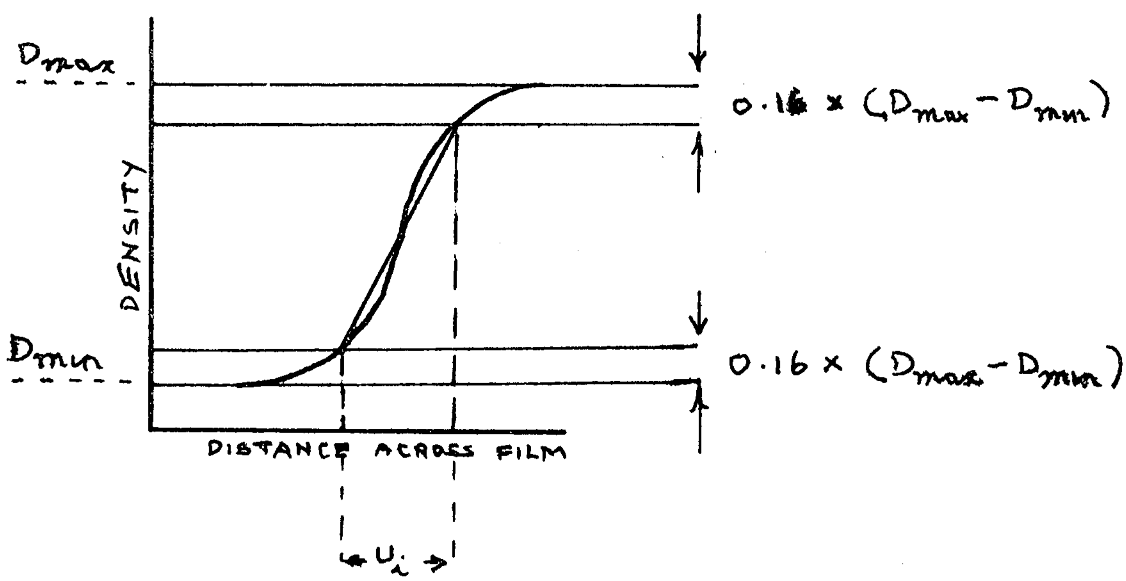


PARALLAX EFFECT.

The radiograph appears unsharp when viewed in the normal manner, i.e., from position B, due to the separation of the individual image details. If viewed along the beam axis, the separate images super-impose themselves to give a sharp image. This effect is particularly noticeable on fine discrete image details.

2.4. Effect of fluorescent salt screens on image sharpness.

2.6. The measurement of inherent unsharpness by the use of a sharp edge; Klasen's method from Philips Research Reports Vol. 1 N°4 241-249.



2.7. The combined effects of multiple sources of unsharpness; $U_T^2 = U_g^2 + U_i^2$ where U_g = geometric unsharpness, U_i = inherent unsharpness, and U_T = unsharpness, (TOTAL).

3. Factors Influencing Image Contrast.

3.1. The place of high contrast and low contrast radiographs in industrial radiography.

3.2. The influence of image density on image contrast; the influence of development conditions on image contrast; the influence of the duration of development on image contrast; the influence of film agitation during development on image contrast. (See Part 1, 3.1).

3.3. The influence of scattered radiation on image contrast: principles, practice, and effect of the use of lead backing, tube diaphragms, filtration at tube and between specimen and film. Effect of filter composition and thickness; composite filters. Principles, practice, and effect of the use of lead intensitying screens; effect of lead screen thickness; general use of lead screens for exposure at 120 kV or higher energy.

3.4. The effect of radiation energy on image contrast. (See also Part 5, 5.1.1.).

PART 6.

THE INTERPRETATION OF RADIOGRAPHIC EVIDENCE.

1. The Scope of Interpretation.

1.1. The functions of the interpreter: correlation of specimen identity with radiographs; verification of correct application of technique; checking adequacy of radiographic quality; identification of defect type and degree of severity; identification of evidence of superficial irregularities and film faults; correlation of radiographic evidence with prescribed acceptance standards; preparation of radiographic report.

1.2. Essential background knowledge: familiarity with the principles and practice of radiography; familiarity with the metallurgy of castings and/or welding; familiarity with appropriate engineering processes and procedures.

2. Equipment and Environment.

2.1. Viewing lanterns: brightness, uniformity of illumination, "high-light" viewer, masking of illuminated area.

2.2. Ancillary equipment: stereoscopes, introscopes, densitometers.

2.3. Film viewing environment: room or cubicle capable of being darkened, freedom from interruption.

3. Film Viewing Methods and Reporting.

3.1. Systematic scanning of radiographs; need to anticipate the unexpected indication; marking radiographs to identify indications; double scrutiny; the preparation of routine and investigatory reports; correlation of radiographic evidence with the results of other tests; the preparation and application of acceptance standards; ASTM standards.

4. The Interpretation of Radiographic Evidence.

4.1. The identification of metallurgical defects: characteristic appearance of void-type flaws arising from gas and/or shrinkage in castings and welds; flaws arising from localised changes in composition (segregation, inclusions in castings and welds); laminar-type defects, influence of flaw orientation on appearance and detectability of laminar-type flaws.

4.2. The identification of flaws in non-metals: voids, cracks, inclusions in plastics; metal inserts in plastic mouldings.

4.3. The identification of flaws in aircraft structures: recognition of structural details, rivets, spot welds, lightening holes, paint and adhesive layers, corrosion, "staggered" cracks, paint-filled cracks.

4.4. The recognition of film artefacts: developer and hypo splashes, developer "flow lines", static, pressure marks prior to and after exposure, screen defects, surface dirt and contamination; the inspection of the film emulsion by reflected light.

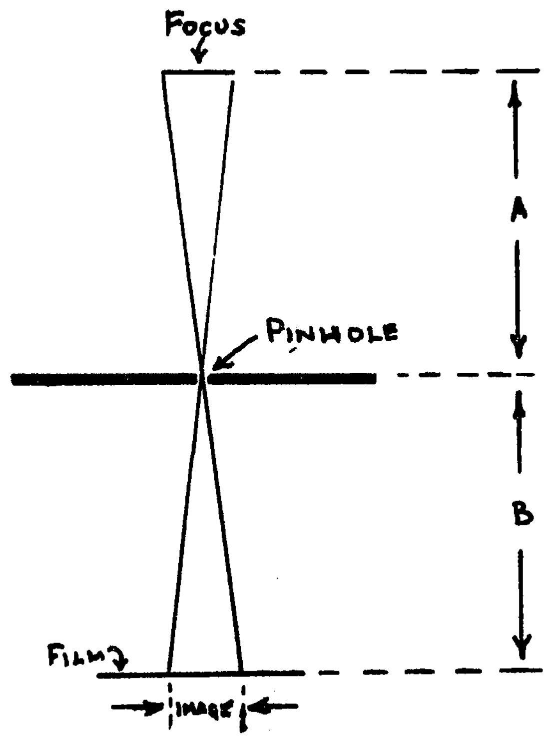
Experiment N°1.

Purpose: to determine the shape and size of the focal spot of an x-ray tube; to note the x-ray emission intensity across the face of the focal spot and target.

Special apparatus required:

1 sheet of lead 100 x 100 x 2 mm. with a central hole 0.5 mm. in diameter. The sheet must be flat and the hole undistorted. The axis of the hole must be at 90° to the surface of the sheet.

Method: place the lead sheet and the film in separate parallel planes. Centre the cone of x-rays on the hole in the sheet of lead so that the central ray is aligned with the axis of the hole.



The method is based on the principles of the "pin-hole" camera. Select a kilovoltage that will not penetrate the lead sheet, i.e., about 60 kV to 80 kV. A short exposure (about 30 secs. to 60 secs., depending upon film type, tube current, etc.) will produce an image of the focal spot and, if the exposure is not excessive, the x-ray intensity distribution across the face of the focal spot. If distances A and B (see sketch) are equal the image will be natural size. If B is increased with respect to A, an enlargement factor of B/A is obtained. A prolonged exposure, while over-exposing the image of the focal spot, will reveal an image of the complete tube target due to x-rays excited by bombardment of the target face by secondary electrons.

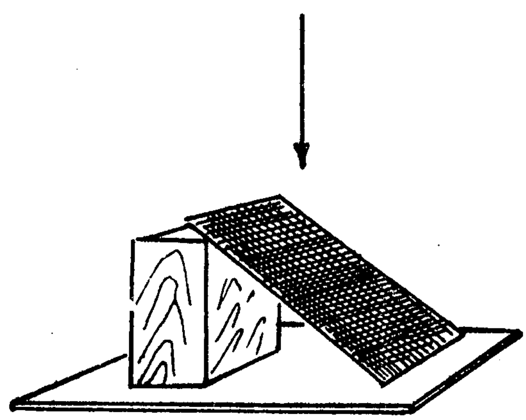
Experiment N°2.

Purpose: to demonstrate the increase in image unsharpness with increasing object-film distance.

Special apparatus roquired:

a piece of fine wire gauze (iron or copper) about 100 x 100 mm.

Method: by means of a simple prop, set the gauze at an angle of about 40° to the film. Using a relatively low kilovoltage (about 60-80 kV) obtain a low density radiograph (about 1.0) of the gauze. Use a film-focus distance of 50 cms.



Note the increasing unsharpness of the images of the wire strands as the distance between the film and the specimen (the gauze) increases.

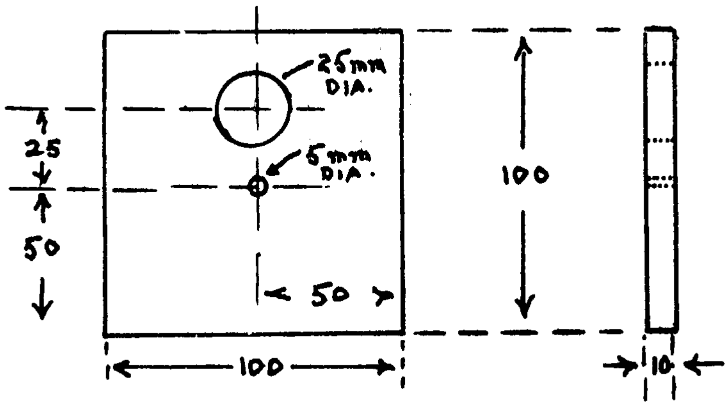
The experiment may be repeated with an identical film-focus distance using an x-ray tube having a smaller (or a larger) focal spot to demonstrate the effect of focal spot size on image sharpness; similarly, using one x-ray tube only repeat the experiment at different film-focal spot distances.

Experiment N°3.

Purpose: to demonstrate the existence of scattered radiation in an industrial radiograph.

Special equipment required:

(1) a lead block 10 mm. thick and 100 mm. square. The block contains two holes, 25mm. in diameter and 5 mm. in diameter as shown in the sketch.



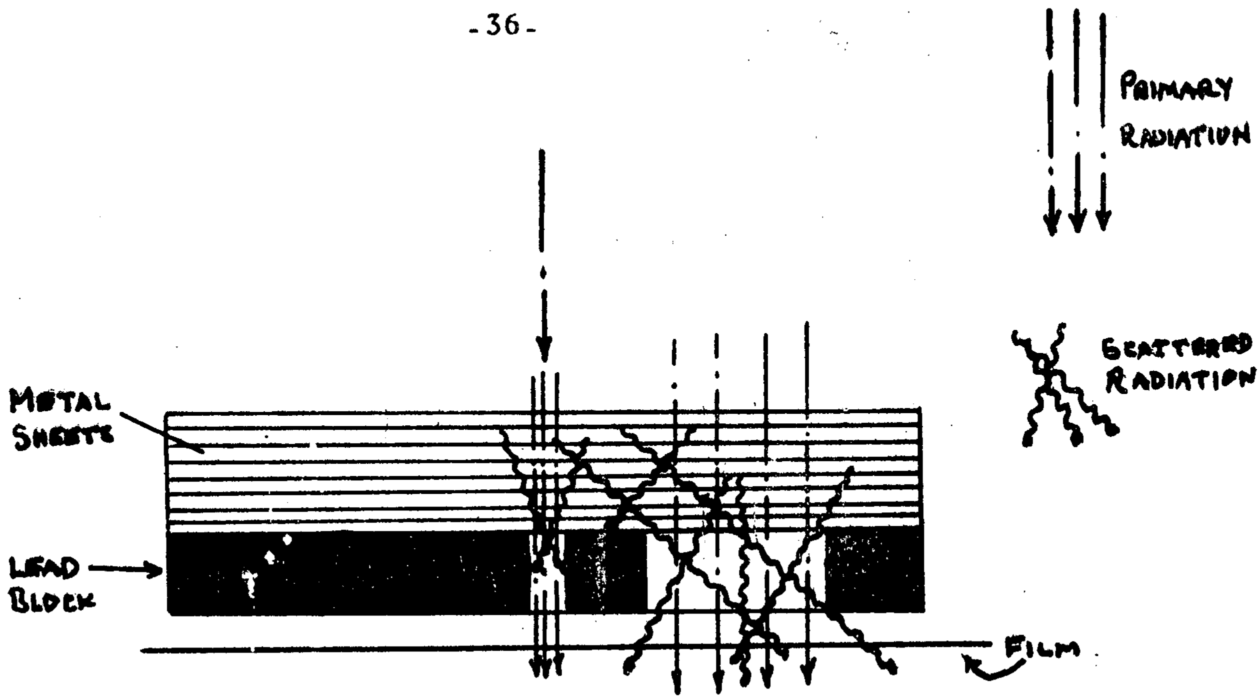
(2) 25 aluminium alloy sheets 2 x 100 x 100 mm.

Principles involved:

When a beam of x-rays passes through a layer of material in radiography, the radiation reaching the film is comprised of (a) primary radiation that has passed undeviated through the layer to form the radiographic image and (b) scattered radiation that is random in direction and which fogs the true image. In this experiment the larger hole transmits both types of radiation while the smaller hole transmits only those rays parallel to its axis, i.e., the primary radiation.*

Method:

Place the lead block on a film and centre the x-ray tube so that the central ray of the beam of x-rays is aligned with the axis of the smaller hole. Place a given number of aluminium alloy sheets on top of the lead block.



Measure the image density formed by the larger diameter hole and the smaller diameter hole. Convert the density values to relative exposure values by means of the characteristic curve of the film. The density (or exposure) for the larger hole is due to primary and scattered radiation. The density (or exposure) for the smaller hole is due almost entirely* to primary radiation. The difference in exposure gives the amount of exposure due to scattered radiation. From the figures obtained find the ratio of primary to scattered radiation. Keeping the kilovoltage constant radiograph increasing thicknesses of plate, taking care to produce approximately the same density of image for the small hole. Plot the ratio of primary to scattered radiation against plate thickness, and comment on the result achieved.

* This statement is not completely accurate, but is adequate for the purposes of this experiment.

Experiment N°4.

Purpose: to demonstrate the effect of an increase in radiation energy on the contrast of a radiograph.

Special apparatus required:

a stepped wedge made in aluminium alloy and ranging in thickness from 5 mm. to 40 mm. by increments of 5 mm. Use an x-ray set with a working range that does not exceed 160 kV.

Method: produce two separate radiographs of the wedge using the same type of film and identical processing conditions in each case, and the following exposure conditions:

Radiograph N°1 : 40 kV, 1 m. film-focus distance.
" N°2 : 110 kV, " " " "

Use an exposure time in each case that produces a film density of 1.5 on the 20 mm. step of the wedge.

Plot a curve of density versus thickness for each radiograph, and observe the slopes of the curves. If the minimum discernible density difference in a radiograph is 0.01, calculate the minimum detectable thickness change that this represents in the two radiographs.

Experiment N°5.

Purpose: to produce a characteristic curve of a radiographic film.

Special apparatus required: None.

Method:

(1) take a sheet of the film to be tested and cut from it a strip 20 mm. wide. Retain this strip in the darkroom in a location where it will be free from exposure to light, x-rays, and gamma-rays.

(2) Using a second piece of film (not that remaining after the removal of the 20 mm. wide strip) find by experiment the exposure time required to produce a density of 4.0 at 80 kV and 1 m. film-focus distance.

(3) using the remainder of the first sheet, expose the film in a series of bands that will yield densities from about 0.4 to 4.0. It is desirable that the majority of the exposures be concentrated over the first quarter of the exposure time scale.

(4) process the film and the strip cut from it simultaneously in the same tank of developer. (The strip will be used for measuring the density for zero exposure).

(5) express the exposure (time x mA) as log relative exposure values and plot these values against measured density. This will give the characteristic curve of the film.

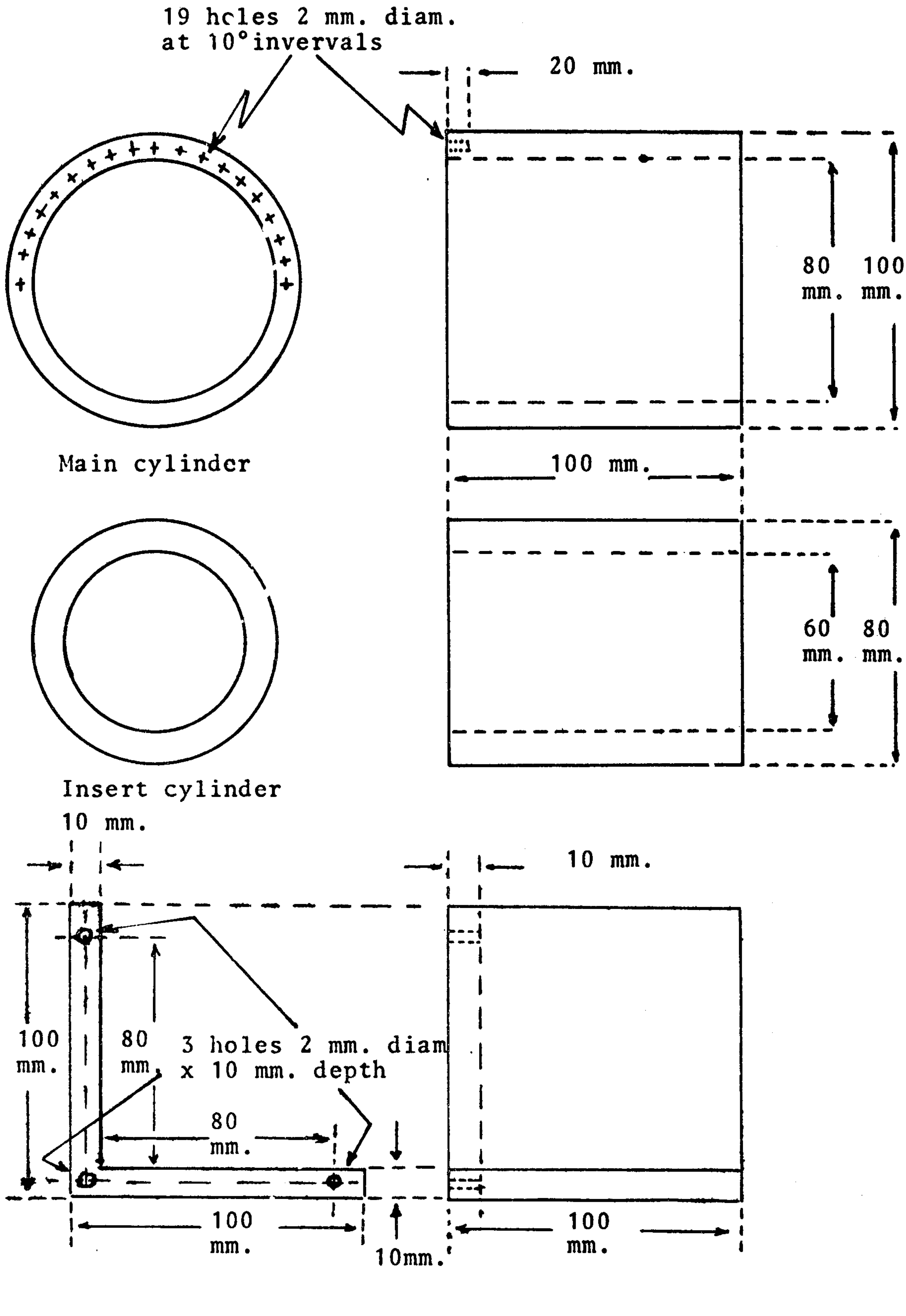
(6) measure the slope of the characteristic curve at a number of density values between 0.5 and 4.0 and plot a second curve of slope versus density.

Experiment N°6.

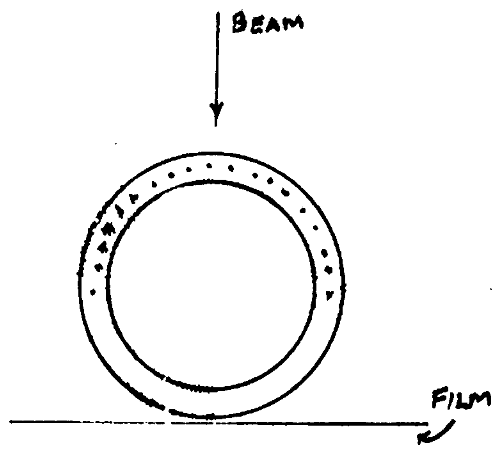
Purpose: to demonstrate the principles of radiographic coverage in certain common configurations encountered in engineering components.

Special apparatus required:

2 cylinders and 1 angled plate as shown in the sketches below, made in aluminium alloy.



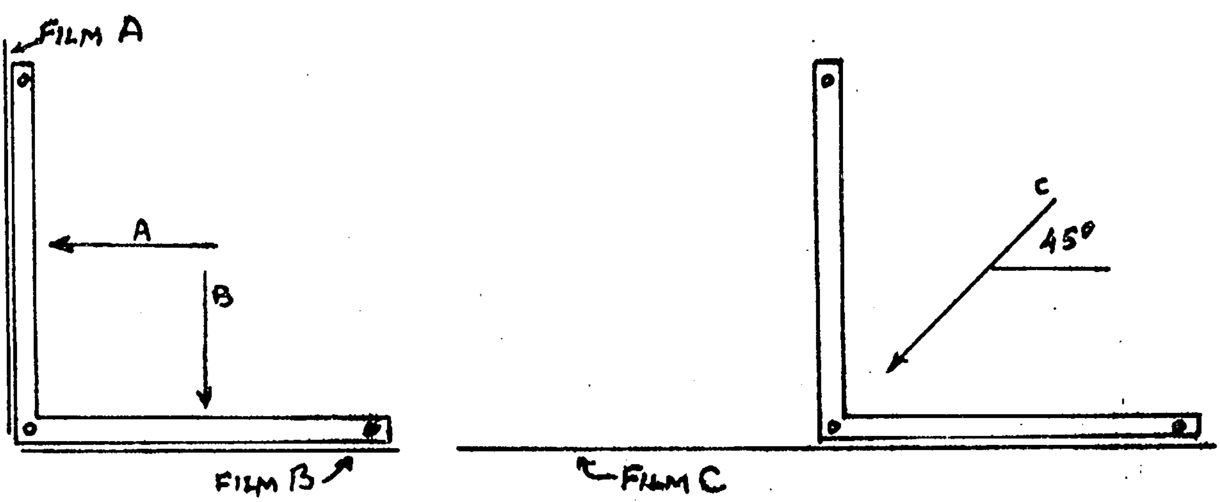
Method: (1) place the main cylinder on a radiographic film so that the 19 drilled holes are positioned in the segment of the wall remote from the film as shown below:



Make an exposure at 80 kV, 1 m. film-focus distance. Count the number of holes that are clearly revealed within the correctly exposed area of the radiograph. Identify those holes that are not clearly revealed. Turn the cylinder through 90° about its longitudinal axis and repeat the exposure on a second film, and note that the holes not previously revealed are now clearly shown in the second radiograph.

(2) Place the "insert" cylinder inside the main cylinder. Using 110 kV and 1 m. film-focus distance, prepare two radiographs as in (1) above. Determine whether overlap of coverage occurs between these two radiographs. If overlap does not occur use the formulae given in Part 4, 4.2.6.2. to calculate the number of exposures required to give complete coverage

(3) Using 80 kV and 1 m. film-focus distance, obtain three radiographs in the manner shown in the following sketch:



Comment on the coverage obtained in each radiograph. Discuss the suitability of exposure N°3 as a general view of the entire specimen, noting in particular the degree of image sharpness obtained over the uppermost parts of the vertical plate.

****

ADDITIONAL EXERCISES.

The students should be given a number of castings and weldments to radiograph. These specimens should be manufactured in light metals and dense metals, and should contain a variety of configurations and a range of thicknesses that will enable the principles given in Part 4 to be applied.

The instructor in charge of these exercises should allow the candidates to work on their own initiative with the minimum of guidance. The candidates' final techniques should be critically assessed, and guidance given where necessary to enable them to be reduced to economical working methods without sacrifice of coverage. In addition to exercises involving practical radiography, the students should be required to learn the use of radiation monitoring equipment. This can be done by allowing them to survey an existing x-ray laboratory, and to verify the adequacy of the safety system employed in a site-radiography situation.

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