The Elements of Shipbuilding Radiography*

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INTRODUCTION

During the war years, there was an enormous expansion in the industrial use of radiographic methods of inspection, especially as a consequence of the demands of greatly increased production for the aircraft industry and the vital need for complete reliability of manufactured components intended for this and other industries.

When used as a supplement to visual or direct methods of inspection, it forms the most dependable means for the detection of hidden internal flaws and, in many types of examination, provides the only dependable method available. The internal inspection of castings and welds, for example, covers an enormous range, in which radiographic inspection has fully established itself. Already many of the largest shipbuilding firms have their radiographic laboratories with sets capable of penetrating considerable thicknesses, while the Admiralty have built up an efficient organization throughout the country. (Fig. 1.)

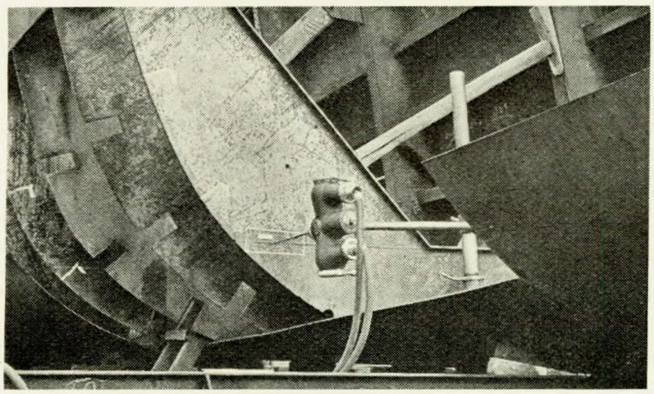

FIG. 1—*Mobile 90 kV Solus-Schall X-ray set in use in shipyard*

There could be no better testimony to the worth of radiography than that payments to contractors working on the construction of the Great Boulder Dam were contingent on the radiographic approval of some twenty-two miles of welded seams.

THE NATURE OF X-RAYS AND GAMMA RAYS

X-rays are short-wave electromagnetic rays having wave lengths ranging from about 1/1,000 to 1/10,000 of those of light. They are generated in special vacuum tubes called X-ray tubes, where electrons are accelerated at a high voltage to bombard a piece of tungsten, or similar material, called the target. The energy of the electrons is turned into heat, together with X-rays which are emitted. The distribution of the intensity of the rays is dependent mainly upon the voltage applied to accelerate the electrons, and Fig. 2 shows curves of intensity plotted against wave lengths for various applied voltages. The minimum wave length of the generated X-rays diminishes with the increase of tube voltage. In addition, the relative intensity of the more penetrating radiation of short waves rises with the increase in the generating voltage.

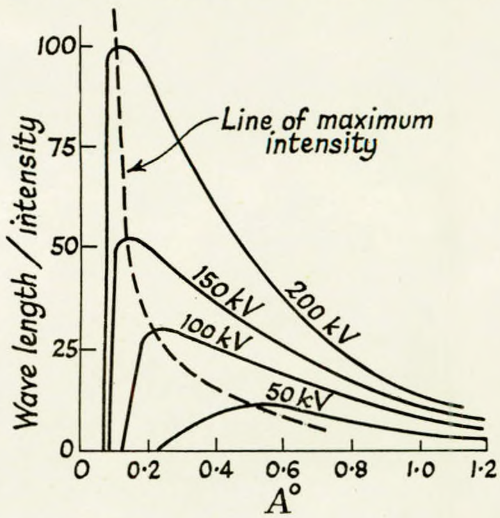

FIG. 2—*Typical wave length/intensity curves for X-rays generated at different voltages*

Gamma rays arise in the spontaneous disintegration of certain "natural" radio-active elements, notably radium and radon and also in artificially radio-active elements, such as cobalt 60, tantalum 182 and iridium 192, and they are similar to X-rays, being electromagnetic in character.

The ability of gamma rays to penetrate increases as their energy increases and these energies are specified in terms of the electron volt (e.v.). They are not emitted in the form of a continuous spectrum as are X-rays but consist of radiations of definite wave lengths as shown in Fig. 3. Actually in the disintegration of a radio-active element there are often a large number of different gamma energies, some of which are more pronounced and control the extent to which the rays will be able to penetrate. With tantalum 182 there are gamma energies

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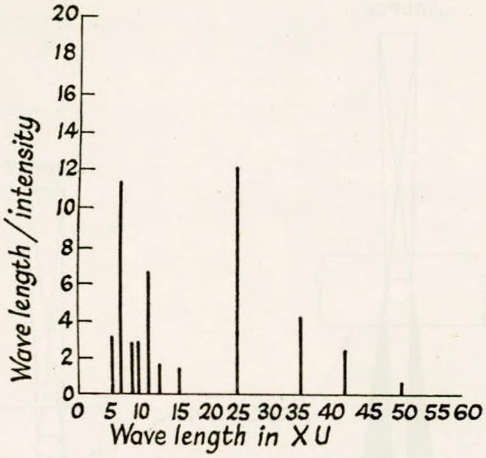


FIG. 3—*Typical distribution of wave length/intensity for gamma rays showing a discontinuous spectrum*

of 1·22 million electron volts (57 per cent) 1·13 mev (37 per cent) 0·22 mev (4 per cent) and 0·15 mev (2 per cent); it is obvious that the penetrating power is in the order of the two highest energies, and, therefore, equivalent to an X-ray set of over a million volts.

The properties of X-rays

There are four chief properties of X-rays and these are enumerated below:—

(1) The rays possess the power of penetrating considerable thicknesses of material opaque to ordinary light.
(2) The rays affect sensitized photographic emulsion in a manner similar to light.
(3) The rays produce visible fluorescence in certain chemical compounds.
(4) The rays cause important and potentially dangerous pathological changes in living tissue.

When a primary beam of X-rays falls upon a specimen, the beam undergoes considerable modification, and its energy is dissipated in three main directions. Part of the energy is expended in the generation of the so-called "secondary rays" which spread out in all directions from and also within the substance. These secondary or "scattered" rays become increasingly troublesome the thicker the substance and actually constitute one limiting factor for penetration in practice. This is particularly the case with the lighter metals and alloys. A further proportion of the energy is lost by absorption within the specimen itself. For a given thickness of substance, the absorption increases in proportion with its atomic number or density, whilst for a given density the absorption obviously increases with thickness. Finally, the remaining portion, after transversing the specimen, passes into the air beyond, eventually to be scattered and absorbed in the medium. It is this which carries an image of the internal structure of the specimen and which activates the photographic film. Only 0·5 to 2 per cent of the original beam ever reaches the film behind the specimen and, of the total radiation falling on the film, the secondary or scattered rays form the greater part.

In practice, the secondary or scattered radiation operates against the sharpness of the final radiograph by causing "fogging". This effect destroys the simple relationship between the thickness of a particular substance and the wave length of X-rays required to effect penetration.

Soon after their discovery, X-rays were found to affect the sensitive silver emulsion of ordinary photographic plates, and according to the intensity of the impinging rays, the sensitive film is blackened to a lesser or greater degree.

The property of X-rays in exciting fluorescence in certain substances such as calcium tungstate and barium platinocyanide is the oldest recorded, since it was by this effect that the rays were originally detected, and this property is used extensively in direct "visual" or screen examination.

The final property is the effect of rays on living cells. It is found that excessive exposure to the radiation produces damaging effects to health, the chief of which are "burns" and changes in the blood conditions resulting in anæmia. In the early experiments in radiography, danger from these effects was always present, but, with modern equipment and ordinary care, the radiographer is quite safe.

THE RESPONSE OF PHOTOGRAPHIC MATERIALS TO X-RAYS

When a specimen to be radiographed is placed in a beam of X-rays, variation in thickness and structure of the specimens results in a point to point variation in the intensity and quality of the emergent beams. If a photographic film is placed in way of the emergent beam, a permanent change takes place in the emulsion and a latent image is produced. By treatment with suitable developers, the latent image, which is itself invisible, is converted into a stable black deposit, in which the blackness at any point depends upon the quality and intensity of the beam falling on that point, together with the conditions of development.

Modern films consist of thin sheets of flexible transparent and non-inflammable "base" material, thinly coated on both sides with a layer of gelatine, in which minute particles of light improve the speed and contrast of the negative, and also accelerate developing, fixing and drying. In addition to film, X-ray paper is obtainable, but sensitized paper is inferior to film in every respect.

PHOTOGRAPHIC DENSITY

If a photographic negative is held up to the light, it will be seen that the intensity of the light emerging from the negative depends on the amount that the negative has been "blackened". In order that the amount of "blackening" may be measured, a system has been devised whereby photographic density, to give "blackening" its technical name, is given by $\log_{10} Bo/Be$ where *Bo* is the intensity of the light which falls on the negative and *Be* is the intensity of the light which emerges on the other side. If a negative transmits all the light which falls upon it, the density will be zero, while if only half the light is transmitted, the density will be $\log_{10} 2 = 0{\cdot}30$.

Similarly, films which transmit 1/10th, 1/100th and 1/1,000th of the incident light have densities 1·0, 2·0 and 3·0 respectively.

A radiograph is made up of areas of different density and it is important to know what is the least difference in density that the eye can distinguish. It has been found that, in favourable cases where the boundary between two regions is sharp, the eye can detect a density difference of about ·01 over a wide range of brightness. In less favourable conditions, where the boundary is diffuse, the density of difference must be much greater. For ideal conditions of viewing, it is found that the density must not exceed 2·0-2·5, whilst detail can be observed with densities 2·5-4·0 by using a high intensity illumination.

TARGET FILM DISTANCE

An important factor governing the intensity of an X- or gamma ray beam is the distance of the film from the target or source. It is reasonably obvious that the intensity of the

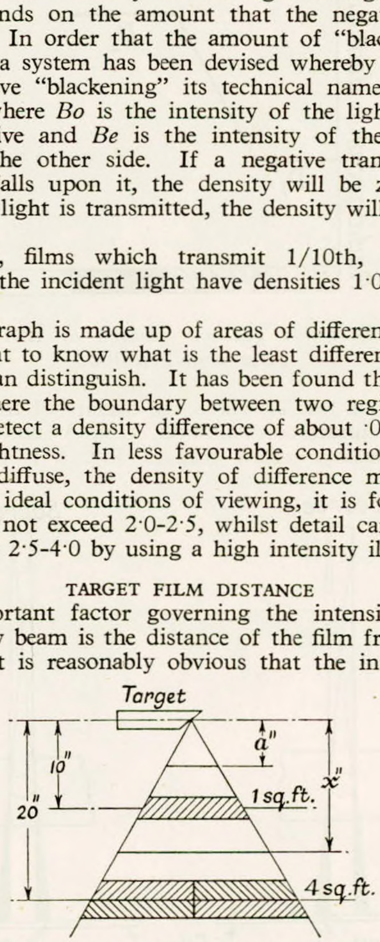


FIG. 4—*Intensity is inversely proportional to (distance from source)*^{2}

beam will vary inversely as the square of the distance from its source, that is, when the beam of rays is emitted from the tube anode, it diverges and covers a progressively larger area as it recedes from the source. Fig. 4 indicates this.

Assume then that the tube current or source strength remains constant and the exposure time must be increased by $\left(\frac{x}{a}\right)^2$ times in order to produce at x a radiograph of equal density or blackening to one produced at a. In practice it is advisable to work with the longest possible T.F.D. consistent with reasonable exposure time.

THE SHARPNESS OF THE X-RAY PHOTOGRAPH

The "sharpness" or definition of a radiograph may be expressed as the rate at which the density of the film changes in the region under consideration. Fig. 5 shows a very sharp change in density, whilst that of Fig. 6 is less sharp and would be less distinguishable, although each has the same change in density, D_1 to D_2. Unfortunately, it is impossible to achieve complete sharpness since the target has a finite size and penumbral shadows are produced, resulting in diffuseness of the photographic image. The nature and extent of the "geometrical unsharpness" can be readily explained by simple geometry.

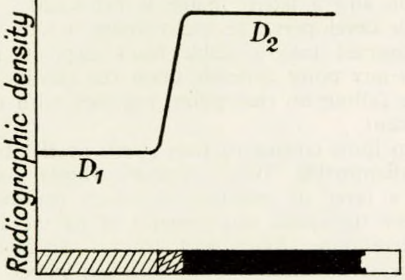


FIG. 5—*A rapid change of density gives good definition*

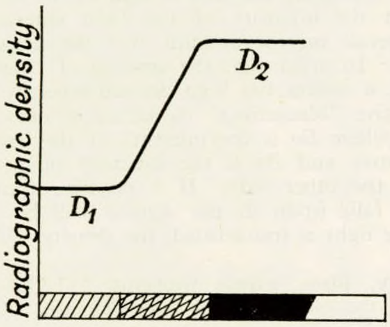


FIG. 6—*A gradual change of density gives poor definition*

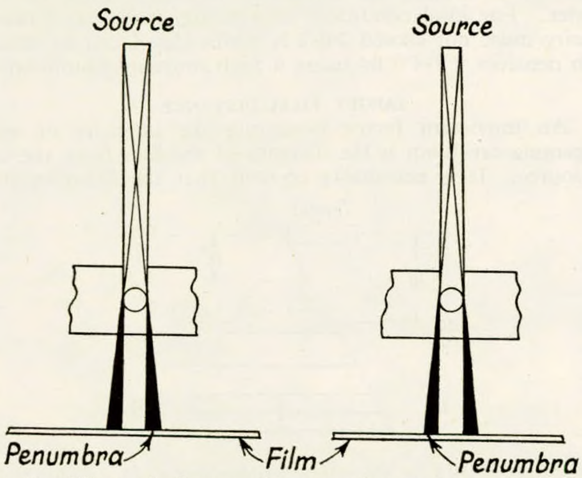


FIG. 7—*Effect of change of source size on penumbral width*

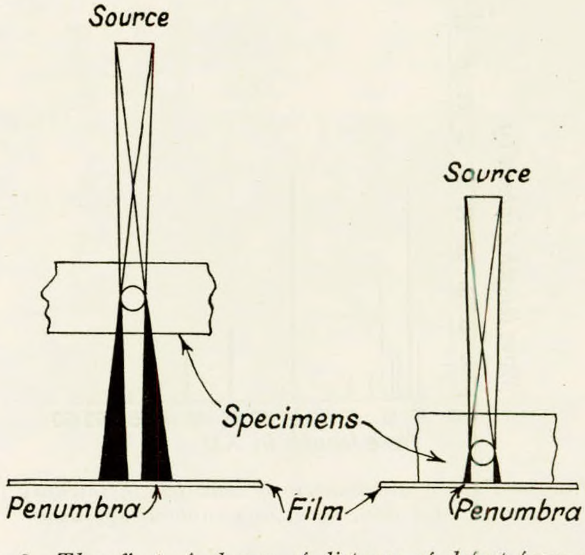


FIG. 8—*The effect of change of distance of defect from plate on penumbral width*

Figs. 7 and 8 show that the penumbral width increases with increasing focal spot area and with increasing distance from defect to film, whilst increase in the distance between source and film reduces the penumbral shadow (Fig. 9). The size of the defect does not affect the width of the penumbral shadow, but, as shown in Fig. 10, there is a minimum size of defect which will produce an umbral shadow at the film, and hence, for any given set of conditions, there is a minimum size of defect which can be revealed by X-rays.

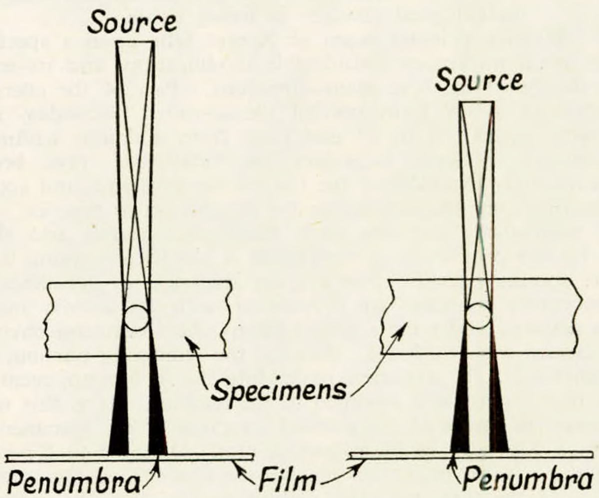


FIG. 9—*Effect of change of distance of defect from source on penumbral width*

If a minimum penumbral diffuseness of edges of ·25 mm. is allowed, it is possible to calculate the relationship between source to film distance and thickness of specimen. Consider a defect at the upper surface of the specimen of thickness t,

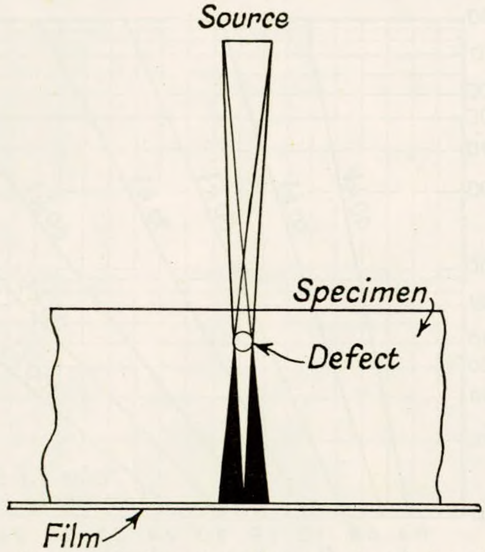


FIG. 10—*Umbral shadow has disappeared and defect will not be detected*

then the width of the penumbral shadow p

$$p = \frac{s \times t}{(f - t)} = 0{\cdot}25 \text{ mm.}$$

s = width of focal spot
f = source to film distance
0·25 mm. = maximum permissible diffuseness.

Thus $\frac{f - t}{t} = 4s$ (when s is expressed in mm).

It is not always possible to achieve this condition, since the intensity of X-rays at a given distance from the source is subject to an inverse square law, so that practical limits are set from the source film distance by considerations of exposure time.

INTENSIFYING SCREENS

Salt Screens

It has been stated earlier that less than 2 per cent of the total energy in an X-ray beam reaches the negative emulsion and since the absorption of X-rays by the emulsion gives being to the latent image, the more energy absorbed, the more exposure time can be reduced, or, alternatively, a greater thickness of material can be penetrated for the same exposure.

As one of the properties of X-rays is to excite fluorescence in certain chemical compounds, it is possible to augment the X-rays by visible light. This is done by surrounding the X-ray film with screens on which the chemical, calcium tungstate is thinly coated. Thus, by this means, a greater use is made of a large proportion of the X-ray beam energy which has been unabsorbed by the negative emulsion, by absorbing it in the chemical coating of the screens, and then "giving it back" to the negative in the form of visible light.

The reduction in exposure time obtained with intensifying screens is considerable, and is in the order of one-quarter to one-fortieth of the exposure time for bare film. Unfortunately the advantage obtained is offset somewhat by the reduction of radiographic quality—mainly definition. There are several reasons for this but the chief one is the effect of grain size in the screen, and the presence of sympathetic glow in adjacent chemical grains. Generally, these screens are employed more for thick steel sections than for light metal radiography, since exposure times are normally short.

Lead Screens

An alternative type of intensifying screen consists of thin sheets of lead foil in place of the chemically coated cards. It is more common to use these screens in the radiography of heavy metals, where they give excellent results. They differ greatly in their mechanism from salt screens in that the intensifying effect is due to electronic emission from the screens instead of light emission, as in the case of salt screens. The reduction in exposure time is not so great as with salt screens, and is of the order of one-half to one-third of the time for bare film.

Lead screens have the further advantage that the screens themselves act as filter for the soft, scattered radiation reaching the film from the various directions, and a radiograph taken by this method always has a cleaner appearance than that taken with salt screens.

The intensification from lead screens depends upon the film, the kilovoltage, and the thickness and kind of metal through which the rays have passed. In the radiography of steel, lead screens begin to give appreciable intensification with thicknesses in the neighbourhood of ¼ inch at voltages of 100-120 kV. At 200 kV., lead screens permit an exposure of about ⅓ of that without screens (intensification factor 3). With the gamma rays and 1,000 kV. gamma rays, the intensifying factor may be about 4. Care should be exercised to prevent any scratches on the lead, as they will show on the film, together with any dust or grease.

THE X-RAY TUBE

The tube consists of two electrodes (anode and cathode) sealed into a vacuous glass vessel. The anode or positive electrode consists of a molybdenum arm supporting a massive copper head in which is embedded a tungsten plate (the target) maintained at an extremely high potential relative to the cathode by a high voltage transformer. The cathode or negative electrode consists of a similar arm supporting a spiral tungsten filament raised to incandescence by the current supplied through a small low voltage transformer. Under working conditions, a stream of free electrons is liberated from the heated cathode filament to be drawn across the tube at enormous and increasing speed towards the attracting anode, where they bombard the target. Some of the energy of the electrons is converted into X-rays, which emanate from the target in all directions, but is restricted by barriers to form a beam, usually at right angles to the tube, and varying in divergence through an angle of about 30 to 40 degrees. A very large part of the energy of the electrons is transferred into heat, which would soon raise the metal of the target to incandescence and cause destruction of the tube. To avoid this, an efficient cooling system must be employed, since for a modern tube operating continuously at 200 kV. 10 m.a., 2 kilowatts have to be dissipated from an area of only 25 sq. mm. This cooling medium varies according to the type of tube and also the circuit exciting it, but generally it is either oil or water. It is pumped under pressure to the back of the tube target and the flow is determined mainly by the amount of heat to be dissipated. When tubes are operated with both electrodes at high voltage (double cable sets), oil is used for cooling as it obviates the necessity for insulating the cooling pump and the circuit, a procedure which would be necessary with water.

Fitted into the X-ray tube window is a filter which has the object of absorbing any soft X-rays emitted from the target and thus reducing the effect of fogging of the radiograph, due to scattered radiation. The amount of soft radiation cut off depends on the density and thickness of the metal filter. Aluminium, copper, tin or lead is used for this purpose, according to the degree of filtration required, and for light metal work, copper filters are common and range in thickness from about 0·5 mm. to 2 mm.

When using filters, the length of exposure to the X-rays must be increased, depending on the type of filter used whilst the photographic contrast of the radiograph is reduced.

THE X-RAY SET

The X-ray set (Fig. 11) comprises, besides an X-ray tube, a high tension generator and control gear. In general, for the high power necessary in industrial X-ray work, the high tension is derived from various combinations of transformer

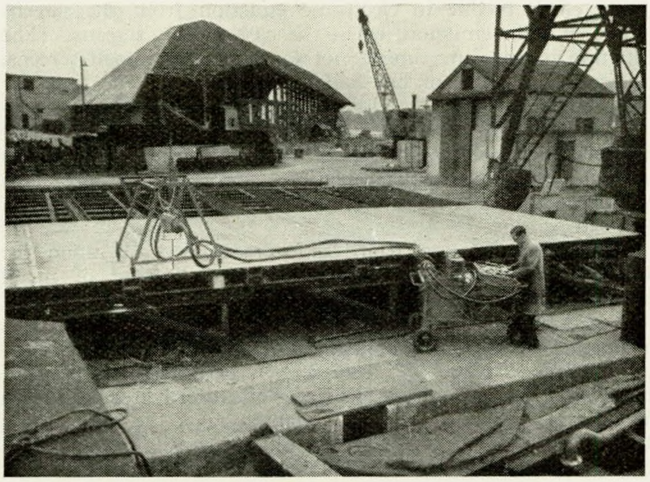


FIG. 11—*Mobile 140 kV X-ray set being used to examine welded plating assembly*

rectifying valves and condensers connected in appropriate circuits such as Villards and Greinacher, so that only unidirectional high voltage is impressed on the X-ray tube. In the majority of X-ray sets, the H.T. transformer valves and condenser are housed in a single earthed tank, and each high tension terminal or lead is taken to the X-ray by means of a shockproof high tension cable. Included in the set is an oil pump used for cooling the X-ray head and it is so arranged that, in the event of the pump failing to fulfil its task correctly, the circuit is broken and X-ray emission stopped.

Whilst it is not intended that the complicated circuits comprising the complete X-ray set should be given, it is necessary to give a very simple outline of the basic circuit with a view to illustrating the amount of control an operator has

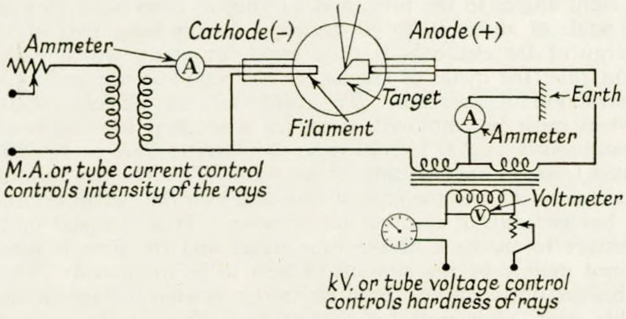


FIG. 12—*A typical fundamental circuit*

over the quality and quantity of the radiation (Fig. 12). On a normal control panel there are three chief variables available:—

(1) Milliamp or tube current control

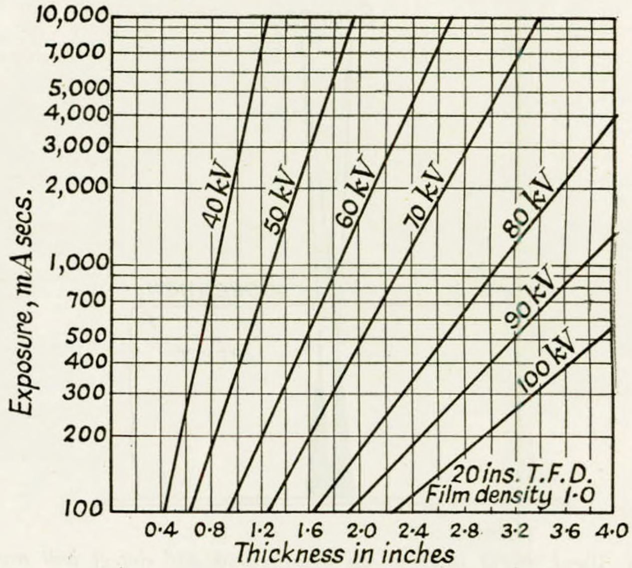
This governs the quantity of X-rays emitted in a given time and any alteration in this control is visible through a milliamp meter.

(2) Tube voltage control

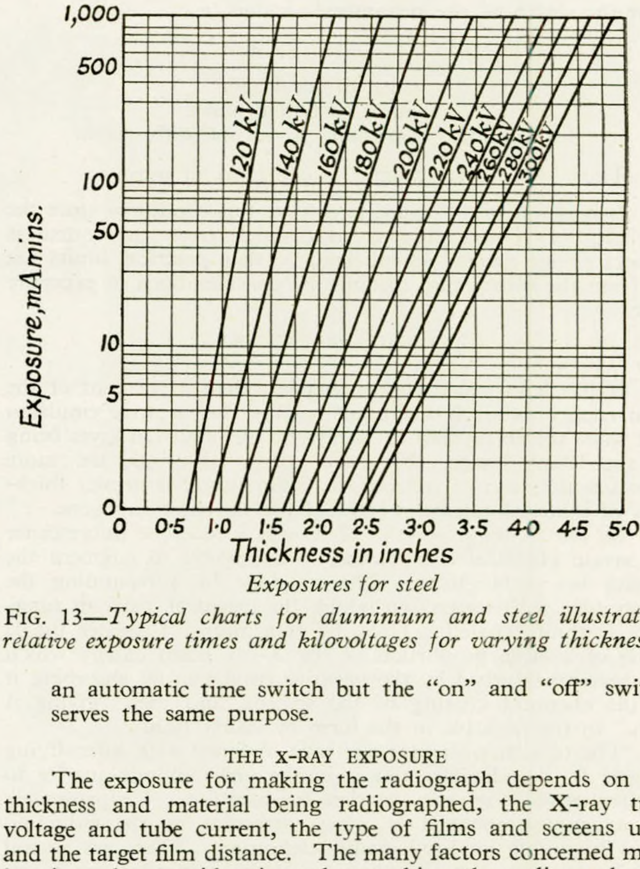
This governs the quality of the X-rays emitted, as any increase in voltage gives increased penetrating power. Due to the difficulties in reading very high voltages, a voltmeter is placed on the primary side of the H.T. generator and the actual kilo voltage available can be obtained by referring to a voltage calibration chart provided by the makers of the set.

(3) Time exposure

Longer exposure time results in a greater quantity of X-rays available for recording an image on a film with a given tube current. Not all control panels are fitted with



Exposures for aluminium



Exposures for steel

FIG. 13—*Typical charts for aluminium and steel illustrating relative exposure times and kilovoltages for varying thicknesses*

an automatic time switch but the "on" and "off" switch serves the same purpose.

THE X-RAY EXPOSURE

The exposure for making the radiograph depends on the thickness and material being radiographed, the X-ray tube voltage and tube current, the type of films and screens used and the target film distance. The many factors concerned must be given due consideration when making the radiograph and it is often helpful to produce an exposure chart, as shown in Fig. 13. The chart is based on a number of fixed factors shown on the diagram and may be constructed readily by using a "stepped wedge". By selecting a range of kilovoltages and exposures, a series of radiographs can be taken and film densities measured for different thicknesses. However, it is important to remember that this chart may vary considerably with the type of set used and also with different X-ray tubes.

It will be seen from the chart that the exposure for a given metal thickness is fixed by the kilovoltage and the product of tube current in milliamperes and time in seconds and termed milliampere seconds. An exposure of 1,000 m.a. seconds is given by a tube operating at 5 m.a. for 200 seconds, 10 m.a. for 100 seconds.

PENETRAMETERS

In a radiological test, it is not only important to be able to interpret flaws, but also to be able to gauge their approximate size and the quality of radiographic image. To do this, it is usual to provide a thin step wedge of the same material as the specimen and known as a penetrameter (see Fig. 14). It should be placed on the side of the specimen remote from the film at the extreme end of the section being radiographed,

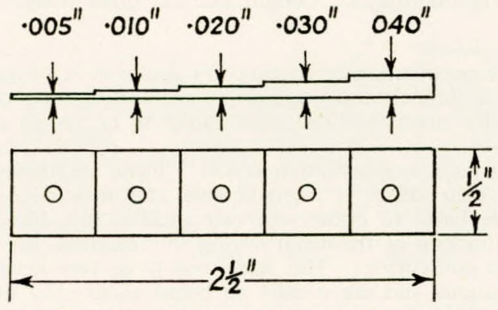


FIG. 14—*A step-type penetrameter*

with the thinnest step farthest from the centre of the section. This represents the worst condition for fault detection, since the rays are at the greatest angle.

The sensitivity is then expressed as a percentage, given by the thickness of the thinnest penetrameter step visible in the radiograph, divided by the maximum thickness of specimen multiplied by 100 per cent. The lower this figure is, the better will be the sensitivity of the test and 2 per cent sensitivity is readily obtainable for all average steel sections.

THE ELIMINATION OF "SCATTER"

It has been previously stated that scattered radiation gives rise to fogging of the film, which impairs the efficiency of radiographic identification. This scatter may be due to several causes. Firstly, the rays striking the floors or walls of a room produce a softer scattered radiation, which reaches the film through the back or sides of the cassette. Secondly, there may be a hole in the specimen through which direct radiation can reach the film, or the specimen may be small so that the radiation can reach the film past the edge of it.

The scatter reaching the film through the back of the cassette is eliminated by backing the cassette suitably with lead, and where it is possible to work with the cassette resting on a small table, it is desirable to have it covered with lead at least ½ inch in thickness. To prevent blackening of the film by scatter around the edges of the specimen, or through holes in it, the edges or holes must be suitably blocked with some X-ray opaque material, such as lead, or opaque plastic containing lead or barium compounds. By this means, it is possible to remove the apparent edge of the specimen beyond the edge of the film, by building up an equivalent thickness of material all round the edge. When using opaque plastic, care must be taken to ensure that no air bubbles or cavities are left in the plastic as these are shown up clearly by the X-ray.

THE DARK ROOM

As X-ray films are sensitive to light rays as well as to X-rays, they must be handled in conditions similar to those used for ordinary photography and in a properly constructed darkroom (Fig. 15); since the correct interpretation of radiographs depends on their quality, considerable attention must be given to the design of the dark room, as well as ensuring that there is complete protection from any scattered X- or gamma radiation arising in the vicinity, as this may affect unexposed film.

The fundamental feature in its design is to have the bench for handling the films when dry well separated from the bench accommodating the film processing equipment. This reduces the possibility of the films being splashed whilst loading or unloading the film holders (cassettes). The dry bench should provide room for housing cassettes and the storing of packets of film in use, as well as a general purpose cupboard and a light tight drawer. Over this bench, racks should be fitted for film hangars, which are used for holding the films during processing. Normal white lighting should be available for ordinary use, but "safe" lighting must be provided for the processing and loading of films.

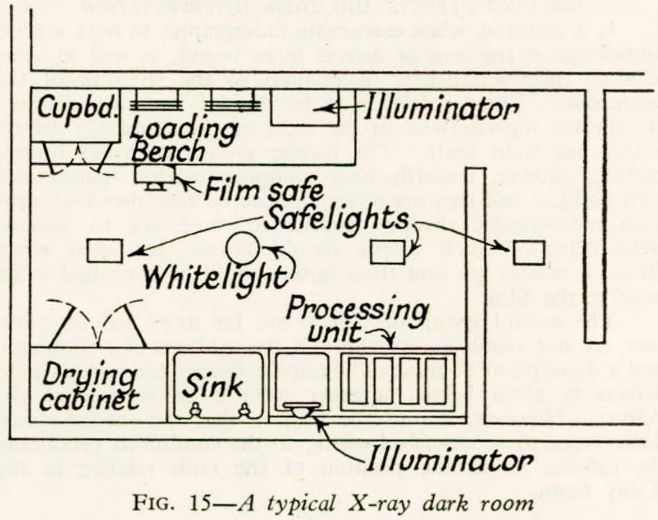


FIG. 15—*A typical X-ray dark room*

In order to obtain radiographs of uniformly high quality and to be able to use exposure charts successfully, it is necessary to have standardized film developing conditions and, for this reason, a thermostatically controlled X-ray film-processing unit should be fitted for the preliminary examination of radiographs whilst wet. A drying cabinet, with hangars and provision for circulating warm air, should be close by for drying wet film. Further ancillary darkroom equipment should include cassettes in which the films are exposed, intensifying screens and processing hangars for holding the films whilst developing, fixing and washing.

HANDLING AND PROCESSING FILMS

It is essential that X-ray film should be loaded into a cassette in a dark room equipped with appropriate safelight illumination and great care should be taken in handling at all stages, as the emulsion layers are easily damaged. Following the exposure, the film is fitted into a developing hangar and immersed in a developing solution, generally at 65 deg. F., for five to seven minutes, dependent on the types of film used. The film should be agitated for a few seconds immediately after immersion, and again after every minute. If the temperature be different from the figure quoted, the developing should be adjusted accordingly to the time temperature charts supplied by the film makers. On completion of development, the film is washed for a few seconds to remove excess developer. It is then transferred to the fixing bath for ten minutes, during which time the chemicals remove the unexposed silver halide from the film, so rendering the image permanent and hardening the emulsion. The film should then be washed for about thirty minutes in running water, drained and placed in a drying cabinet where the temperature of the warm air should not be in excess of 90 deg. F.

It is essential that all radiographs should be viewed on an illumination which should be provided with masking diaphragms to reduce the illuminated area to the size of the film, so preventing the eye being dazzled by a bright surround to the film.

WELDING DEFECTS AND THEIR INTERPRETATION

It is essential, when examining radiographs, to have a good knowledge of the type of defects to be found, as well as some idea of their seriousness in relation to the strength of the connexion. These defects may be divided into two classes: (1) surface inperfections in the weld or plate and (2) defects within the weld itself. The former group comprises under-cutting, pitting, underflushing chipping marks, spatter and torn surfaces and they are of importance because they may produce radiographic shadows similar to those due to internal weld defects. Such marks should always be noted when taking a radiograph and these notes should be consulted when reading the film.

The second group of defects are far more serious, since they are not visible except through the medium of radiograph, and a description of these radiographic images for various weld defects is given below, together with a description of the defects. However, it must be realized that the shadows may differ from those described owing to the conditions producing the defects, or to the position of the fault relative to the X-ray beam.

Undercutting

This is caused by using a welding current which is too high and under fatigue conditions it is very serious. On the radiograph this defect shows as a continuous or intermittent dark ribbon like a line with wavy edges and is generally parallel to the length of the weld either as a single line or double line (tram lines).

Porosity

This is caused by trapped gas bubbles in the weld metal and they are either spherical or elongated (pipes). They are generally caused by the sulphur content, moisture and the nature of the coating of the electrodes. The effect is not very serious if the bubbles are regular. Porosity is revealed as dark shadows with sharp rounded edge contours.

Cracking

This can occur either in the weld metal or parent metal and there are four main varieties of cracking:—
(*a*) longitudinal; (*b*) transverse; (*c*) crater; and (*d*) hairline.

The basic cause of all cracking is due to a very high local stress.

(*a*) Longitudinal cracking is caused by the weld metal shrinking and a high stress being set up. It is generally associated with the first run made and is not likely to occur if a heavy run is used.

(*b*) Transverse cracking is due to ending a run of electrode.

(*c*) Crater cracking is not very common and is generally the fault of the electrodes.

(*d*) Hairline cracking is sometimes found to occur when using an automatic welding machine.

Under ideal conditions, a crack is revealed as a dark wavy line. Sometimes the line is broken, and the ends of each shadow lie side by side and occasionally bifurcation occurs at the ends.

Slag inclusions

These are patches of slag which are trapped either in the sides of the weld, due to undercutting in a multirun deposit, or in the root. The former produces the characteristic tram lines on the radiograph, whilst the latter forms a single line in the centre of the weld. Slag inclusions can be distinguished from blowholes, as the dark shadows are irreglar and there are no rounded edges. As the inclusion absorbs radiation, all forms give images having lower contrast than that of gas defects of the same dimensions. Small inclusions appear as ill defined dark spots.

Lack of fusion

This term is applied to any lack of union between (a) parent metal and parent metal; (b) weld metal and parent metal; (c) weld metal and weld metal. It is often caused by the presence of scale or the use of too low a welding current at too high a speed. This defect is not always detected by radiography but when it is, the image takes the form of a dark line with a sharply defined edge. It is a serious defect.

Incomplete penetration

This is caused by the failure of the weld metal to penetrate into the root of the weld. It is revealed as a continuous or intermittent dark line or band running along the centre of the weld and parallel to its length. Both edges may be straight or one may be straight and the other wavy.

Casting defects

The examination of coatings for faults to be found therein is often a difficult task requiring some insight into the study of foundry practice. The chief faults to be found are listed below:—

Hot tears or contraction cracks. These are always serious because their effect is unpredictable and may cause failure. They are liable to occur wherever there is any hindrance to free contraction of the metal during solidification, for example, in angles and corners. Hot tears tend to be very irregular and discontinuous and are usually so broad as to offer little difficulty in their detection.

Segregations. In the steel making process, deoxidization of the steel is carried out whilst the steel is molten by the addition of various compounds. Aluminium is sometimes used for this purpose and, if the resulting slag becomes mixed with the steel whilst being poured into the mould, segregates are formed which may reduce the mechanical strength of the metal to a very low value. Normally, this defect is of rare occurrence.

Inclusion and chaplets. It is not unusual to find pieces of scale and sand embedded in the metal. If the sand is present in a flocculent condition, it is relatively harmless, but where the hard surface dressing of the mould flakes off to form scabs, these are liable to cause a leakage through the metal walls, especially when they become oriented nearly normal to the surface. Similar effects are caused by the imperfect fusion of chills and of studs or chaplets.

Blowholes. These have typically rounded contours and are commonly due to the entrapping of gases from the mould during pouring operation. They are frequently found in flanges where they may become elongated into fine capillary pipes.

GAMMA RAY SOURCES

An important property of a radioactive substance is that the quantity of radiation emitted is not constant but reduces with time. The time taken for the intensity to fall by half is known as the "half life" and in a further "half life" interval of time the intensity will fall to one-quarter of the initial value and so on. This value of "half life" is very important since it governs to a great extent the useful time a source can be used before it is no longer able to produce a satisfactory radiograph. The variation in the half life times for different types of sources is very marked, ranging from 1,590 years for radium to 3·7 days for radon. Between these two extremes there are the artificial radioactive elements of cobalt 60, half life 5·3 years, tantalum 182, half life 120 days and iridium 192, half life 70 days.

For radiographic purposes an important factor is the quantity of radiation which is emitted in relation to the size of the source, since it is possible with a small source size to achieve better definition in the radiograph. This relationship is known as specific strength and outstanding in this respect is the gas radon which, as it absorbs readily in charcoal, can be concentrated into a very small space. The specific strength of the other materials are many times smaller than that of radon, with radium having the lowest value.

When the intensity of the artificial radioactive elements fall below a useful workable value the source may be returned and reactivated to any desired intensity below a maximum saturated state above which it is impossible to rise. The irradiation of a source may take many months, depending on its final strength and size of source required. Iridium activates more rapidly than cobalt or tantalum and can generally be obtained more easily, but due to its relatively short half life it is convenient to have several of these sources so that one is always at a high intensity.

Sources supplied by the Atomic Energy Research Establishment (A.E.R.E.) are in the form of cylinders having diameters equal to their length, of dimensions 2 × 2 mm., 4 × 4 mm., and 6 × 6 mm., with special sources of 1 × 1 mm. and ½ × ½ mm. Each source is enclosed in a small aluminium capsule and can be manipulated by means of a specially designed rod. Radium and radon are contained in similarly shaped capsules, but other designs of capsule can be made if preferred.

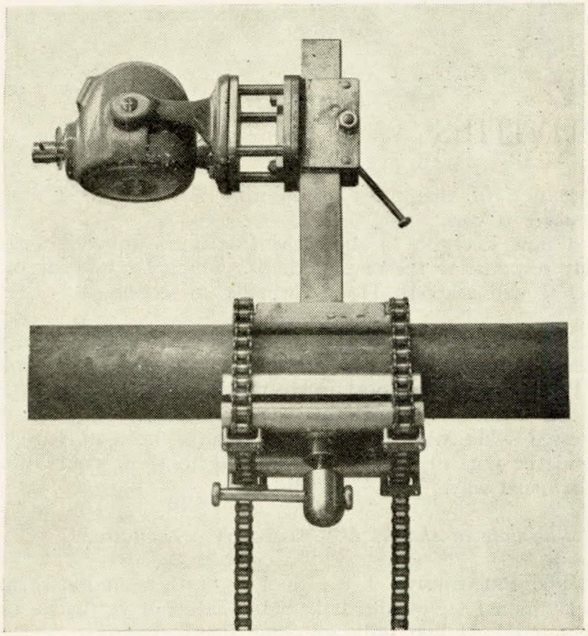


FIG. 16—*Gamma examination of pipe showing ingenious portable stand developed for this type of work*

These capsules are placed in a heavy metal container (Fig. 16) preferably tungstun or a similar metal of high atomic weight, to facilitate handling of the source. There are one or more conical outlets to the "bomb", as it is called, which may be opened at will so that a well defined beam results. As radiation still arises in all directions from the source itself, the shrouding merely serves to reduce the intensity of the radiation in all but the beam direction.

DIFFERENCES IN THE INTERPRETATION OF RADIOGRAPHS MADE WITH X-RAYS AND GAMMA RAYS

Gamma rays from radium correspond roughly in penetration to X-rays generated at 1,500-6,000 kV. and even with iridium 192 it would be 300-400 kV. and, in consequence of this, their penetrating power is very great.

This high penetration produces an image contrast markedly lower than that obtained with X-rays, particularly on thin sections where a much lower kilovoltage will still penetrate. Consequently, the images of defects are more difficult to detect and the finer flaws may not be recorded.

Further differences arising from the use of gamma rays are greater image magnification due to the short source film distance used to partially offset the long exposure and the great penumbral effects due both to the relatively large sources from which the rays emerge and to the shorter source film distance. Generally, this latter effect is less important when using a radon source as explained previously. However, for these reasons, no gamma ray sources, except iridium 192, should be used for steel thicknesses below about 2 inch unless they offer the only other means of obtaining a radiograph of that part. Iridium 192 can be used with success on steel thicknesses of ½-2½ inch and so there is plenty of scope for its use in the shipyard.

PROTECTION FROM RADIATION

Quite apart from the danger of shock due to the extremely high voltages generated in the X-ray equipment, the radiographer has to contend with the effect of radiation. Although modern apparatus is safe in the sense that it throws a well defined beam of rays, danger from scattered radiation still exists. Such a scatter may be of considerable intensity and be excited from the tube windows, any surrounding structure or from the specimen. It is not always possible to be able to screen the operator, though where possible the control decks should be housed in a separate lead or barium protected cubicle with provision for preventing entry into the tube room whilst X-rays are being emitted. If work is undertaken in a large open engineering shop, or in the open air, mobile lead screens may be used, though even these are not always practicable.

Generally, precautions taken against exposure to gamma rays are greater than for X-rays, as the effects of the former on the human body are less well known, and because, owing to the simplicity of the apparatus as compared with X-ray sets, the dangers are less obvious and essential precautions may easily be neglected. Since emission of gamma rays cannot be prevented, the amount of radiation absorbed by the body can only be reduced to a safe value by keeping well away from the source of rays or by enclosing the bomb in a protective casing of lead or heavy alloy when not in use. However, when radiography is in progress and the source is being placed in position, a certain degree of proximity is unavoidable. Generally an occasional over exposure is permissible, but it must be appreciated that, within limits, it is immaterial whether an exposure is received in frequent small doses or occasional large doses. One of the effects of over exposure is a diminution of the white blood corpuscles and a reliable safeguard consists in having periodical blood counts made by a pathologist.

The minimum safe distance for exposure to an unshielded gamma ray beam from 200 mgm. of radium is about 11 feet and, during radiography, the operator must stand well away from, and out of, the main beam. If the examination is made in a closed space, it is advisable to leave the room until the exposure is completed. In the workshops, it is necessary to rope off an enclosure containing the structure under examination; where this is impracticable, a suitable display of "Danger—Gamma Ray Exposure" notices will usually have the desired effect in keeping factory personnel at a safe distance.

SIGNIFICANCE OF RADIOGRAPHIC FINDINGS

It will have been appreciated that the interpretation of radiographs presents considerable difficulty and calls not only for high quality testing but also for wide experience before X-ray examination is reliable and accurate. Unfortunately, even when these have been achieved, it is not always possible to say exactly what effect the defect will have on the strength of the item in question, especially when it is subject to alternating stresses.

In special cases of boiler drums, welding has been rejected if serious defects are shown up in radiographic examination, but in the majority of cases it is not possible to do this, even though the welding has slight defects, and the examination mainly serves in producing a better quality weld by its psychological effects on the welders concerned. Generally, X-ray inspection is best applied for developing welding techniques and the establishment of standards, detecting faulty workmanship and the rejection of faulty castings or components. In these fields alone there is an enormous scope for the use of radiography and, perhaps, when more equipment is in use, data will become available to enable tasks, now impossible to radiography, to be accomplished.

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INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting held at the Institute on Tuesday, 16th September 1952

An Ordinary Meeting was held at the Institute on Tuesday, 16th September 1952, at 5.30 p.m. Mr. R. W. Cromarty (Chairman of Council) was in the Chair, supported by Mr. S. Hogg (Vice-Chairman) and Mr. A. Robertson (Honorary Treasurer); fifty-three members and visitors were present.

The CHAIRMAN, opening the meeting: Before calling upon our President to give his Address, may I, on behalf of the Institute, give him a very warm welcome and our best wishes for a very successful year of office? (*Applause.*) Owing to the fact that he was abroad, Lord Howard was unable to be with us on the night of his election, but that does not mean to say that in the meantime he has not been taking an interest in the affairs of the Institute. Far from it, because you all had a letter asking you to make his year of office a memorable one by increasing the membership, which is a thing we all want to do. I think it could easily be done by each one of us introducing a member; that would double the membership in no time. I am sure we should like that to happen, my Lord, during your Presidency.

The President has also interested himself in the National War Memorial Building; he has taken a very keen interest in that and he intends in the very near future to send out a letter under his own signature to 1,500 shall we say "subscribers"—or, at any rate, we hope they will be! In that case we shall see the Memorial Fund and Building on very firm foundations, perhaps in more ways than one, during the term of your year of office. I now call upon Lord Howard to present his Address.

The PRESIDENT, Lord Howard de Walden, then delivered his Address (see p. 203).

The CHAIRMAN: We have all listened with great interest to the President's Address. As one would expect from the chairman of a progressive shipping company, his Address has been most stimulating. Were it not for the fact that the Address is not open to discussion, I am quite sure that there are many here tonight who would like to comment on the many parts of a ship which, he so rightly considers, need modernizing. Engineers and shipbuilders, and even some shipowners, are ultra-conservative and very, very slow indeed to make any changes. It is only through being prodded that they make them. We must thank Lord Howard for doing that tonight and also for giving so much of his time and care to the preparation of this most stimulating Address, as I am sure you agree it was.

I now ask you to show the Institute's appreciation by a hearty response to the vote of thanks which I now propose and which I will ask Mr. Hogg formally to second.

MR. S. HOGG (Vice-Chairman of Council): It is a great pleasure to me to be asked to second this vote of thanks to the President for his most interesting Address. I am sure you will all agree with me that our Chairman has admirably expressed what was in our minds and I need only formally second the vote of thanks and ask you to show your approval in the usual way.

The vote of thanks was passed by acclamation.

The PRESIDENT: I was looking rather anxiously at the water which I see by the desk, but I have not yet had a chance to reach it! I can only say that I am extremely pleased to be here. I was rather in fear and trepidation of loosing off some remarks to people who have forgotten more than I shall ever know about the subject, and it was only because I had been told that the subject would not be discussed afterwards that I faced the ordeal! Now it is over, and all I can say is that I am only too pleased to have the honour to be your President. I hope that during the time I am President the affairs of the Institute will flourish, and that they will continue to flourish for all time. Thank you very much indeed for your reception. (*Applause*).

The proceedings then terminated.

Autumn Golf Meeting 1952

In brilliant weather the Autumn Golf Meeting was held at Hadley Wood Golf Club on Thursday, 11th September 1952.

Fewer members than usual attended; twenty-two members participated in the morning Medal Competition, which was won by Mr. J. M. Mees with a net score of 75. Messrs. J. G. Edmiston and W. J. D. Middleton tied for second place with 76 but Mr. Edmiston won on the best score for the last nine holes.

Twenty-four members took part in the afternoon Bogey Greensome Competition. Messrs. R. Ward and R. M. Wallace came in first with 3 down, while Messrs. W. J. D. Middleton and J. A. Campbell Brown were second with 4 down.

The prizes were presented during the tea interval by Mr.

A. Robertson (Convener of the Social Events Committee). Mr. Mees was presented with a travelling clock, while Mr. Edmiston received a flask. Messrs. Ward and Wallace gained a tankard each, and Messrs. Middleton and Campbell Brown were each awarded a set of heat resisting mats.

A resolution was passed conveying a vote of thanks to the Hadley Wood Golf Club Committee, to be relayed through the Secretary, Mr. H. M. Williams; the arrangements which had been made for the meeting, including the excellent luncheon and tea, were much appreciated by all present. A vote of thanks was also passed to the prize donors for their generous support—Messrs. E. F. J. Baugh, J. H. F. Edmiston, A. Robertson and W. Tennant.

At the close of the meeting Mr. Robertson made an appeal on behalf of the Marine Engineers' National War Memorial Building Fund and drew attention to the possibility of members subscribing under a covenant scheme covering seven years, whereby income tax could be recovered by the Institute thus almost doubling the amount donated, and he urged all members to take advantage of this scheme wherever possible.

The meeting terminated with a hearty vote of thanks to Mr. Robertson, proposed by Mr. J. C. Lowrie.

Sydney Local Section

On Monday, 1st September 1952, at 8 p.m., the Sydney Local Section held a meeting at Science House, Gloucester Street, Sydney. Mr. H. A. Garnett (Local Vice-President) was in the Chair and 110 members and guests were present. Before introducing the main business of the meeting, the Chairman welcomed back Capt.(E) G. I. D. Hutcheson, R.A.N.(ret.) (Honorary Secretary) from his trip abroad; Captain Hutcheson, in reply, described his visit to the Institute headquarters on 16th June when, by special invitation, he attended a meeting of the Council.

Dr. W. L. Hughes then delivered a lecture on "Modern Merchant Shipbuilding"; he gave a comprehensive review of the subject and his most interesting paper was well illustrated by lantern slides. A discussion followed in which Messrs. Hutcheson, Ferrier, Robertson, Purves, Buls and Lees took part. A vote of thanks to the author was proposed by Mr. C. McLachlan and seconded by Mr. A. H. Miller.

Membership Elections

Elected 13th October 1952

MEMBERS

Robert Atkinson, B.Sc.
Charles Norman Blakey
William George Carter
John Donaldson
Nicholas Douzinas
Andrew Edward Carr Glass
Richard George Greaves
Herbert James Hawke
Jack Hodgson
John Morley Ingram
Kenneth M. D. Johns
William Patrick Nicoll
Charles Graham Robertson

ASSOCIATE MEMBERS

Rajnish Bahl, Lieut.(E), I.N.
William Watson Calvert

ASSOCIATES

Donald John Allcock
Daljit Kumar Bhandari, Sub. Lieut.(E), I.N.
David Boyd
John Benney Burdon
George Henry Burgess
Geoffrey Devereux
Robert Dixon
Denzil Samuel Crawford
John Gilbert Gibson
Desmond Graham
John Halket
George Hawkins
John Norman Hesketh
Francis Home
Albert Edward Jillians
Gordon McLagan Kellet
Ronald Harry Neatham
Cyril George Nightingale
Warwick William McCormick
Colin Campbell Robinson
Gordon John Roy
Robert Sproul

GRADUATES

George Ronald Baldock
James Dennis McBride
James Francis Tobin

STUDENTS

Terence Harrison
Ian John Hoskison
Mohamed Zahir Navaz
Nariman Jamshedji Shapoorjee

PROBATIONER STUDENTS

Peter Eric George Albert
Derek Beaver
Robert George Chesterton Bennett
Kenneth Nichol Bexon
Frederick Percy Bradley
John Francis Carter
Richard John Christie-Gammie
Robert Brian Clark
John Ormond Coldron
James Marsden Collis
Allan Douglas Coston
David Richard Cusdin
Peter Robert Davies
Brian John Down
William Sidney Thomas Dowse
Frederick Charles Draper
Ronald Fenton
James Green
Roy Robert Grenham
Philip David Hall
James Arthur Hitch
Michael Jim Artois Holloway
Robert John Holmes
John Valentine James
Brian Frederick George Kenyon
Ernest Brian Kitching
Roy Edward Lacey
Ian Herbert Livingstone
Roy Mason
Michael George Mayhew
George Ernest McCarthy
John Edward Milham
David Malcolm Nicol
David Partrick
Reginald Edwin Pilcher
Brian Denton Rolls
H. K. G. Sampson
Harold David Senior
Raymond Leo Simmons
John Colin Taylor
K. Taylor
Terence Charles Thorpe
John William Tilby
Jeffrey Robert Towll
Rex Young

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER

James Sloan, M.Sc.

TRANSFER FROM ASSOCIATE TO MEMBER
William Hood Martin
Henry Edmund McGrady
Frank Wilson

TRANSFER FROM STUDENT TO MEMBER
John Peter Hempson Brown, Lieut.(E), R.N.

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER
Stanley James French

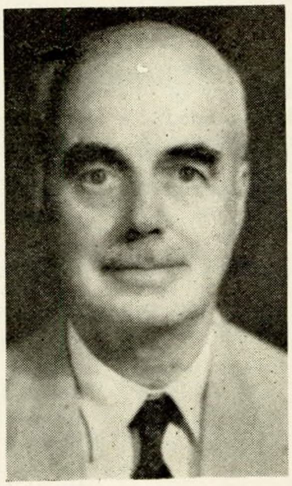
Kenneth Jones Heavisides
Glynne Lewis

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER
George Edward Acklam
George Richard Harvey

TRANSFER FROM STUDENT TO GRADUATE
Allen Bellingham, B.Sc.

OBITUARY

FREDERICK GEORGE RITCHIE (Vice-President 1937-42, and Member 2621) was born in Dundee in 1886; he was educated there at the Morgan Academy and served his apprenticeship with the Caledon Shipbuilding and Engineering Co., Ltd., from 1901-05. On completion of his apprenticeship he went to sea with the Brocklebank and Shire Lines until August 1909, when he obtained a First Class Board of Trade Certificate. He joined the Sarawak Steamship Company as second engineer of the s.s. *Kuching* in October 1909 and left her to join the Straits Steamship Co., Ltd., as chief engineer in 1911, at the age of twenty-five. In 1913 Mr. Ritchie was appointed surveyor of ships, Penang, but in 1914 he joined the firm of Fittock and Adam, marine surveyors of Singapore, an association which established an interest in that district which was to last for the rest of his life. On the death of the surviving partner of the firm, Mr. Ritchie took over the business and the name of the firm was changed to Ritchie and Bisset, consulting engineers and marine surveyors.



For many years he was the senior surveyor in Malaya for the British Corporation of Shipping and Aircraft, and also of the Bureau Veritas, American Bureau of Shipping, and Det Norske Veritas. As consultant to the Straits Steamship Co., Ltd., he was responsible for the design of many of their vessels, including the t.s.s. *Kedah,* a 19-knot passenger vessel, and the post-war t.s.m.v. *Rajah Brooke.*

During the second World War Mr. Ritchie was deputy superintendent sea transport officer for Malaya; he was captured on leaving Singapore and was a prisoner of war in Sumatra from 1942 to 1945. He played a very valuable part in the production at Singapore of the Diesel engine when, during the war years, machinery was not available from the United Kingdom. A committee was set up in Singapore, of which Mr. Ritchie was a principal member, and 8-cylinder Diesel engines of 550 h.p. were entirely designed and built at Singapore, the first of which was produced and ready for Admiralty trials in seven months.

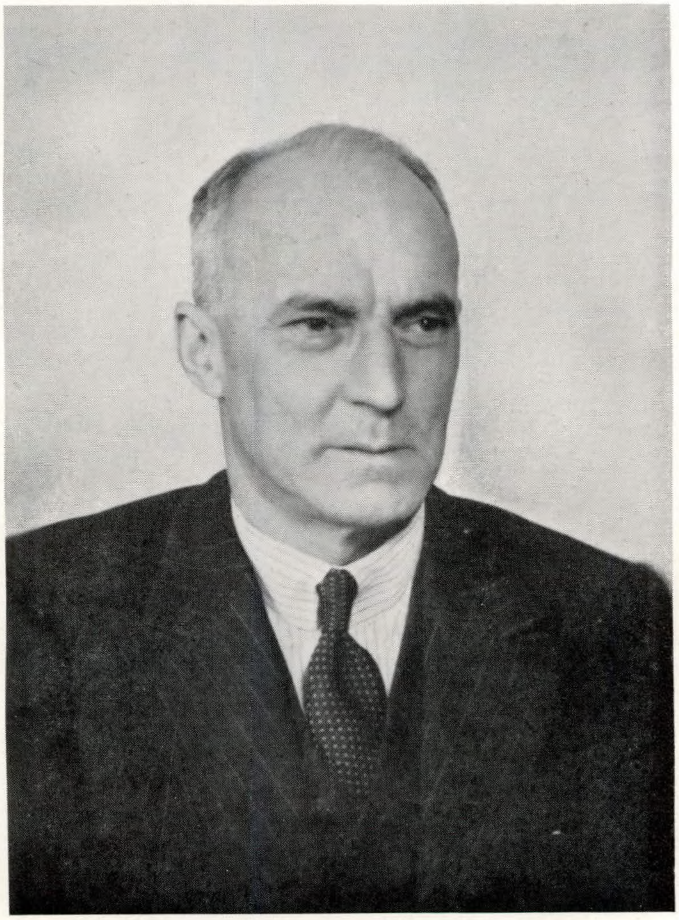
Mr. Ritchie was a director of United Engineers, Ltd., from 1932 onwards, and became Chairman of the company in 1947. He was also a director of the Singapore Cold Storage Co., Ltd., the Singapore Dairy Farm, Ltd., Jackson and Co., Ltd., and the Dunlop Malayan Estates, Ltd.

In 1950 he was appointed adviser to the Malayan delegation of the E.C.A. office in Bangkok, and was also a member of numerous committees on shipping and engineering in Malaya.

For his war services, and for his services in the interests of shipping and engineering generally in Malaya, Mr. Ritchie was awarded the O.B.E. in 1951. He died at Singapore on 8th August 1952. He was a Member of the Institution of Naval Architects, the Institution of Mechanical Engineers, and the Institution of Engineers and Shipbuilders in Scotland. He was a Member of the Institute from 1912 and served as Vice-President for Singapore from 1937 until 1942.

WILLIAM DOWLING (Member 8139) was born in 1887 and served his apprenticeship with Sir John Jackson, Ltd. (1903-07) and Barclay Curle and Co., Ltd. (1907-09). He was a seagoing engineer with T. and J. Harrison of Liverpool from 1909-17 and obtained a First Class B.o.T. Certificate. In 1917 he was assistant to the managerial staff of H. and C. Grayson, Ltd., for nine months and then for two years he was chief assistant surveyor to T. C. Salter of Liverpool. In August 1919 he joined the Hain Steamship Co., Ltd., as superintendent engineer and served the company in this capacity until his retirement, owing to ill health, in 1949. Mr. Dowling spent the last years of his life at his home in Shrewsbury; he died on 23rd September 1952. He was a Member of the Institute from 1936 and was also a member of the Institution of Mechanical Engineers and of the Liverpool Engineering Society.

ALLUN GRIFFITH (Member 11114) was born in 1903. His apprenticeship was served with Grayson, Rollo and Clover Docks, Ltd., Liverpool, from 1919-23. The next ten years were spent at sea in the service of T. and J. Harrison, and he obtained a First Class B.o.T. Steam Certificate. From March 1935 until his death on 10th September 1952, Mr. Griffith was employed by Grayson, Rollo and Clover Docks, Ltd.; he was an assistant manager at South Works, Wapping, Liverpool, until January 1940, assistant manager at the Birkenhead dockyard until January 1941, when he was promoted manager, and general manager (Birkenhead) from 1946-49, when he assumed the general managership of the company. He was a Member of the Institute of Welding and was elected to membership of the Institute in 1947.



Mr. H. S. Humphreys.

HERBERT SEPTIMUS HUMPHREYS

Members of the Institute and shipping representatives from all over the country assembled at the Gravesend Parish Church on the 9th September 1952 to pay their last tributes to Mr. H. S. Humphreys, chief engineer superintendent of the British Tanker Company, who passed away following an operation on the 5th September. He was sixty-three years of age.

He was of seafaring stock, being the seventh son of Mr. George Daniel Humphreys, a Trinity House pilot, and for his wife he chose the daughter of Captain James Smith, a Senior Master in the British India Company.

His early education was obtained at Margate College and Clarance College, Gravesend, and his apprenticeship was served with Messrs. A. W. Robertson and Company of the Royal Albert Docks. He joined the Atlantic Transport Line as a junior engineer in 1910 and in due course obtained his First Class Board of Trade Certificate, and early in the 1914/18 war was serving as senior second engineer on the transport *Minneapolis* when she was torpedoed. Subsequently, in 1916, he transferred to the Royal Navy as engineer lieutenant and in 1919 was demobilized with the rank of lieutenant commander. For a period he served with Lloyd's Register of Shipping as a ship and engine surveyor at Belfast until late in 1920 when he joined the British Tanker Company as an engineer superintendent. In 1937 he was promoted to assistant chief engineer superintendent, and in 1942, in succession to Mr. J. J. Mackenzie, he became chief engineer superintendent, which position he occupied until his death.

Mr. Humphreys joined the Institute of Marine Engineers in 1919 and was elected to the Council in 1930. He continued active Council work until 1948. In 1936 he was awarded the Denny Gold Medal for his paper on "The Care and Maintenance of a Modern Diesel Engine Tanker Fleet" and the same year he was elected Chairman of Council. As a Member of Council he took a keen interest in the activities of the Institute and, besides serving on the Membership Committee and the Executive and General Committees of the Guild of Benevolence, he represented the Institute on Lloyd's Register Technical Committee, the Royal Naval Reserve Advisory Committee, the Merchant Shipping Advisory Committee and the Marine Oil Engine Trials Committee. He also served on the Technical Committees of the Chamber of Shipping and the Shipping Federation and was a Member of the Council of the Shipping Federation and a Member of the Institution of Naval Architects. Many of those closely associated with him have often wondered how Mr. Humphreys, with his onerous duties in the British Tanker Company, could carry on with so many other activities, for, besides taking a keen interest in cricket and golf, he was also for many years an active supporter of the Gravesend Conservative Party.

The strain of the war, with its severe casualties, was particularly heavy on Mr. Humphreys and his British Tanker colleagues. He, however, took a prominent part in the preparation of specifications for wartime tanker construction and, together with technical representatives of other oil companies, he took a leading part in the development and design of the prototype fireproof ship's lifeboat.

He will long be remembered as a superintendent engineer of outstanding ability and one who continually worked for the improvement of the status of the marine engineer. For years he advocated an alternative scheme of training for the marine engineer and we are glad that, before he passed from us, the Ministry of Transport had decided to put a new scheme into operation. With the passing of Mr. Humphreys, we have lost a colleague who, by his own ability and integrity, gained the respect of the shipping and shipbuilding industries, and, as one of the younger school of marine engineers, I would like to express our appreciation of the fatherly guidance and advice he was ever pleased to give.

A. LOGAN, *Member of Council.*