GAMMA RADIOGRAPH OF REFRACTORY-LINED VESSELS AND COMPONENTS

by

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Materials Science Division

August 1978
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GAMMA RADIOGRAPHY OF REFRACTORY-LINED VESSELS AND COMPONENTS

by

N. P. Lapinski

ABSTRACT

Materials used in coal-conversion systems are exposed to high pressure, high temperature, corrosive and erosive gases, and liquids containing particulate matter. These severe environments necessitate an assessment of the integrity of components to prevent premature failures. Gamma radiography was evaluated as a viable technique for testing components in the laboratory or after operation in situ. Penetrators (image-quality indicators) were developed for refractory-lined vessels and transfer lines, and exposure times for various combinations of refractory-steel thicknesses were determined. Radiography with $^{60}$Co was performed on gasifier vessels, combustor vessels, and critical transfer lines in existing pilot plants using the experience gained through laboratory experiments. The results show that gamma radiography is a practical and effective method to detect critical conditions in coal-conversion system components.

INTRODUCTION

Prevention of premature materials failure in coal-conversion components necessitates an assessment of the integrity of the refractory before and during plant operation. Gamma radiography seemed to be an especially suitable method for examining laminated structures such as refractory-lined gasification vessels and transfer lines (see Figs. 1-3).
Before going into details concerning some experimental radiography conducted on mockups in the laboratory and on actual gasification-plant components, we will review some basic characteristics of X- and gamma radiation. X rays and gamma rays are forms of electromagnetic radiation, as are visible light, ultraviolet light, infrared waves, radio waves, and cosmic rays. The wavelength region of the electromagnetic spectrum covered by X- and gamma radiation is not absolutely defined, but for our present purpose, we will consider the wavelength range from 0.001 to 1000 Å (1 angstrom = 10^{-10} m). The general properties of X and gamma rays may be summarized as follows.

1. Invisible and pass through space without transference of matter.
2. Propagate in straight lines.
3. Not affected by electric or magnetic fields.
4. Evidenced on photographic film by density.
5. Capable of ionizing gases.
6. Differentially absorbed by all media.
7. Able to damage or kill living cells and to produce genetic mutations.

Many of these properties apply to radiography, the most useful being film blackening, straight-line propagation, and differential absorption in matter.
Gamma radiation, unlike X-radiation, is nuclear in origin. Only a few radioisotopes decay by simple emission of gamma radiation. Usually, gamma emission occurs after the nucleus emits alpha or beta rays. Since gamma rays have neither charge nor appreciable mass, the isotope remains unchanged after the emission of gamma radiation; only the available energy is reduced, leaving the product nucleus in a more stable state. Gamma-ray energies are characteristic of particular isotopes. The energies vary widely, from a few thousand electron volts (keV) to several million electron volts (MeV).

Important definitions related to radioisotopic sources are listed in the appendix.

II. LITERATURE REVIEW AND LABORATORY TESTS

Two literature searches were conducted to assess the applicability of radiography to ceramic-lined steel structures, and to determine the current state of the art. Key words used in these searches included: gamma radiography of refractories, X-ray radiography of refractories, refractory-lined vessels, refractory, piping, nondestructive testing, and nondestructive evaluation of refractories and ceramics. The search yielded only two articles in addition to ANL Quarterly Reports. In his article, Schackelford presents a nomograph to calculate parameters for radiography of refractories. The accompanying text only explains the use of the nomograph. Borbas et al. in their paper describe the application of gamma-radiation absorption techniques to measure the density of refractories.

Results of this search indicated the need for laboratory tests of ceramic-steel composites and the development of penetrameters (image-quality indicators). A 1.2 x 1.27-m (48 x 50-in.) full-scale mockup of the refractory/steel laminate cross section of the Battelle-Columbus gasifier [228-mm (9-in.) refractory, 6.35-mm (0.75-in.) steel] was assembled to evaluate the crack-detection capability of gamma radiography with refractories of such a layered structure. Gamma radiographs of the mockup were generated after the refractory had air-dried for 5 days. The entire casting was divided for crack mapping into four quadrants, each separately radiographed on four 35.6 x 43.2-cm (14 x 17-in.) sheets of Eastman Kodak Type AA film. The source-to-film distance of 1.2 m (48 in.) required an exposure time of 5 h when a 2.22 x 10^11-Bq (6-Ci) ^{60}Co source was used. The radiographs revealed internal cracks, which varied in length from 7.7 to 28 cm (3 to 10.5 in.) and in width from 1.58 to 4.75 mm (0.062 to 0.187 in.). These cracks did not coincide with numerous visible surface cracks.

A second set of radiographs was taken after the mockup was fired and thermally cycled. The radiographs revealed that curing increased the number and size of cracks. Refractory moisture content was not a significant factor in obtaining good radiographs. The average difference in photographic density between radiographs taken shortly after the refractory was poured and those taken after curing was only ~0.41.
At the same time, radiographic experiments were conducted to relate the film density to refractory thickness and to determine the spatial resolution limits. The refractory used was high-density alumina into which 6.25-mm (0.25-in.)-wide slots were cut. The slotted refractory was placed on 65.6-mm (2.625-in.) steel plate, and supplementary molded refractories were added to complete the mockup of the cross section of a typical air-cooled pilot-plant gasifier jacket. A steel step wedge was placed adjacent to the mockup, and radiographs were taken. From these radiographs, the relationship between the film density and the refractory wall thickness was established\(^6\) and normalized. This relationship indicated that refractory thickness could be determined to ±6.3 mm (0.25 in.), using normalized film densities.

Additional studies on the sensitivity of film density to refractory-thickness reduction have been conducted using a step wedge with 15 steps [6.3 mm (0.25 in.) deep by 12.5 mm (0.5 in.) wide], cut from a high-density aluminum oxide molded refractory. A densitometer was used to determine film density at each reduced thickness. The results were similar to those obtained with the slotted samples, indicating that refractory-thickness reduction can easily be measured by gamma radiography if a calibration is available to allow the film density to be related to thickness.

To quantitatively determine the resolution of radiographs, penetrameters had to be developed. The penetrameters, constructed from Norton 4190 Alundum refractory, were 11.4 cm (4.5 in.) long, 6.3 cm (2.5 in.) wide, and 6.35 mm (0.25 in.) thick. The penetrameters had through-hole diameters of t/2, t, 2t, and 3t (t equals the penetrameter thickness). Laboratory tests were conducted to compare the placement of penetrameters on both the source and film side of a refractory/steel laminate mockup. The refractory/steel mockup consisted of 28 cm (11 in.) of KAOTAB refractory and 6.7 cm (2.75 in.) of steel. The gamma radiographs indicated that placement of the penetrameter on the film side is preferable to placement on the source side, because in the former case all the holes can be seen in the penetrameter, whereas in the latter case only the 3t and 2t holes can be discerned. This is due to the large distance required between the object, penetrameter, and film when the penetrameter is placed on the source side in the conventional manner. This large distance degrades the image.

Disk-type penetrameters were also developed and fabricated from high-density refractory. They were 2.54 cm (1 in.) in diameter and 0.635 cm (0.25 in.) thick, with a 1.27-cm (0.5-in.)-dia through-hole in the center. The disk-type penetrameters were constructed especially for use in radiography of refractory/steel laminated components.

III. FIELD TESTS AND RESULTS

Field gamma radiography was performed on the gasifier vessel at Bi-Gas, and on the combustor vessel and transfer lines at Battelle. These
tests were conducted to establish exposure parameters, assess field-implementation difficulties and requirements, and develop methods to obtain panoramic gamma radiographs. All the radiographed components had a refractory lining.

Refractories that are common in coal-conversion systems include Castolast G, KAOTAB, ALFRAX 101, ALFRAX BI 57, and ALFRAX BI. Table I lists the manufacturers' stated physical properties for these refractories after curing. Severe environments such as high temperature, high pressure, and thermal cycling can cause degradation and cracking of these refractories.

<table>
<thead>
<tr>
<th>Refractory</th>
<th>Manufacturer</th>
<th>Alumina(^a) Content, %</th>
<th>Density, kg/m(^3)</th>
<th>Maximum Service Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castolast G</td>
<td>Harbison-Walker Refractories</td>
<td>97.7</td>
<td>2610</td>
<td>1815</td>
</tr>
<tr>
<td>KAOTAB</td>
<td>Babcock and Wilcox</td>
<td>95</td>
<td>2699</td>
<td>1815</td>
</tr>
<tr>
<td>ALFRAX 101</td>
<td>Carborundum</td>
<td>99.45</td>
<td>2980</td>
<td>1870</td>
</tr>
<tr>
<td>ALFRAX BI 57</td>
<td>Carborundum</td>
<td>94.6</td>
<td>1460</td>
<td>1815</td>
</tr>
<tr>
<td>ALFRAX BI</td>
<td>Carborundum</td>
<td>78.80</td>
<td>1398</td>
<td>1760</td>
</tr>
</tbody>
</table>

\(^a\)Al\(_2\)O\(_3\).

Schematic diagrams of pressure-vessel cross sections are shown in Figs. 1 and 2. Figure 1, a cross section of the Bi-Gas gasifier vessel, represents the thickest section thus far radiographed. The 9.04-cm (3.562-in.) steel shell (SA-3870) is circumferentially lined with 3.76-cm (1.5-in.)-OD, 3.29-cm (1.297-in.)-ID steel (SA 213T22) water-coolant tubes, which are insulated with 46 cm (18 in.) of ALFRAX BI 57 and an inner layer of precured ALFRAX 101 brick 11.43 cm (4.5 in.) thick, set in place with ALFRAX 3449 mortar.

The cross section in Fig. 2 is of the combustor vessel at Battelle. The 1.9-cm (0.75-in.) steel (SA-A3870) shell is lined with 23 cm (9 in.) of a monolithic high-density refractory (KAOTAB). At intervals of 61 cm (24 in.), vapor barriers are installed around the circumference of the steel vessel to attenuate gas flow should the refractory crack. Part of a refractory-lined transfer line is shown in Fig. 3. This is a 35.5-cm (14-in.)-OD Schedule 20 steel pipe lined with 23 cm (9 in.) of KAOTAB refractory with a 10-cm (4-in.) bore.

During the field test, a \(^{60}\)Co source was used and a technique was developed for obtaining useful radiographs. The procedures, described in Sec. IV, can serve as a reference for future gamma-radiographic inspections of lined coal-conversion plant components. The techniques permit one to obtain gamma radiographs of refractory-lined vessels and piping to show possible discontinuities in the refractory, anchor orientation, and bore definition.
An example of a gamma radiograph showing anchor orientation and air pockets beneath a vapor barrier is shown in Fig. 4. (See Fig. 2 for the cross section.) The voids, typically 3.8-7.6 mm (0.149-0.299 in.) long and 1.3-2.5 mm (0.051-0.098 in.) wide, were discernible in each radiographed elevation. Figure 5, a radiograph of part of the Bi-Gas vessel (see Fig. 3 for the cross section), shows a typical void at the center. The discontinuity is 23 cm (9 in.) long and 0.64-1.6 cm (0.251-0.625 in.) wide. The clarity of the coolant tubes is most significant, because future radiographic examinations may reveal whether the tubes have undergone any corrosive attack.

Bore, contour,\textsuperscript{10-12} and erosive wear in refractory-lined piping can be seen by means of gamma radiography. Figure 6 is a schematic diagram of one type of refractory-lined transfer line that was radiographed. This item was radiographed before and after about 200 h of solids circulation. Figures 7 and 8 are schematic diagrams showing the pre- and postcirculation conditions, respectively, of the refractory in the Y section. Figures 9 and 10 are schematic diagrams showing the condition of the refractory before and after solids were circulated through the elbow section. As a result of these findings, it was necessary for Battelle personnel to modify and install a system that would reduce the erosion rate.

![Fig. 4. Radiograph of Section of Battelle's Combustor Vessel Showing Voids beneath Vapor Barrier and Orientation of a Hanger](image-url)
Fig. 5. Radiograph of Section of Bi-Gas Gasifier Showing Void in Center of Film

Fig. 6. Schematic Diagram of Refractory-lined Transfer Line at Battelle. Neg. No. MSD-65119.

Fig. 7. Schematic Diagram of Y Section before Solids Were Circulated through System. Neg. No. MSD-65125.
Fig. 8. Schematic Diagram of Y Section after Solids Were Circulated through System. Neg. No. MSD-65124.

Fig. 9. Schematic Diagram of Elbow before Solids Were Circulated through System. Neg. No. MSD-65127.
Like most nondestructive tests, gamma radiography has its limitations. The vessel cross section shown in Fig. 1 is about at the limit of useful penetration for $^{60}\text{Co}$. Bore definition of refractory-lined pipe having a 51-cm (20-in.) OD with a 10-cm (4-in.) bore was marginal. In spite of this, gamma radiography is a valid nondestructive test to detect changes in refractory-lined vessels and piping.
IV. GAMMA-RADIOGRAPHIC PROCEDURES FOR FIELD TESTS

Although laboratory tests helped establish half-value layers for the most common refractories used in coal-conversion component linings (see Table II), field tests established procedures for in-situ gamma radiography. These newly developed procedures will help in future implementation of gamma radiography.

V. Equipment and Field-implementation Considerations

While conducting field radiography at the various coal-conversion test facilities, Argonne personnel have encountered some difficulties that should be mentioned. First, the container that houses the $^{60}$Co source must be transported onto the structure. The container may weigh 450-650 kg (1000-1500 lb). An elevator or hoist able to safely lift the weight must be available. Second, to generate panoramic radiographs of equal densities, a hollow tube with ID nominally 2.8-3.8 cm (1.125-1.5 in.) should be inserted into the center of the vessel and secured at the top flange, as shown in Fig. 11, to accommodate the flexible tube containing the $^{60}$Co source. This method allows the source-to-film distance to be maintained at a constant value during the exposure. The film should follow the contour of the vessel to maintain the equal distance desired between the source and the detector. Flexible cassettes satisfy this requirement; they should be secured around the diameter of a vessel (by tape, rope, or both). Lead figures and numbers are necessary for identification.
Film types we have used successfully have been DuPont Type XDT 75 and Eastman Kodak Type AA. The film is always used with 0.254-mm
(0.01-in.-) thick lead foil screens at the exposure side and back side. The
screens increase the photographic action on the film, largely by emitted
electrons and partly by the secondary radiation generated in the lead; in
addition, they absorb scattered radiation.

Special penetrators should be fabricated of the same refractory
material used in the lining of the component to be radiographed. If it is im-
practical to fabricate penetrators from the material being radiographed,
a refractory material should be chosen that has a density as close as possible
to the one undergoing radiographic
testing. If there is a choice between a higher- and lower-density refractory,
it is better to choose the latter because the contrast sensitivity of the pene-
trator image on the film would then be less than 2%.

Penetrators found useful in our work are disks (see Fig. 12) with a thickness equal to 2% of the
total thickness of the refractory-steel
cross section of vessels or the total
refractory-steel thickness of piping. The diameter of the hole is equal to
the penetrator thickness. The image of the penetrator on the
processed film will indicate a con-
trast sensitivity of 2%. Penetrators
should be placed on the film side of the component being inspected. Placement of the penetrator on the source side of the component would result in a
distorted image, because the object (penetrator)-to-film distance is too
great. A penetrator should be placed on each film that is exposed.

B. Single-wall Radiography

Panoramic gamma radiographs7 are taken of refractory-lined vessels
at the elevations of interest. Panoramic radiographs are taken by securing
film entirely around the vessel in the manner shown in Fig. 13. A 60Co source
of at least 1.85 x 1012 Bq (50 Ci) is inserted into a hollow tube to the desired
elevation and maintained for the duration of the exposure. Each film should
be identified at each radiographed elevation. Film identification can be made
as shown in Fig. 14. Exposure times may vary from elevation to elevation,
depending on the vessel-wall thickness, refractory thickness, and the absence
or presence of internal components.
Laboratory experiments\textsuperscript{10} to detect the effect of moisture content in the refractory on photographic density showed a density difference of 0.41 between as-cast and cured KAOTAB refractories using the same exposure time. Field tests of ALFRAX BI 57 refractory-radiographed before and after refractory curing indicated an exposure-time difference of about 50%. Refractory moisture content had no effect on image quality or sensitivity in either instance.
One way to determine exposure time is to calculate the refractory equivalence to steel and refer to a conventional $^{60}\text{Co}$ exposure calculator. As a rule of thumb for determining approximate refractory/steel equivalence for high-alumina refractories, 7.6 cm (3 in.) of refractory is about equal to 2.54 cm (1 in.) of steel. Another method successfully used to determine approximate exposure times for vessel walls is to take gamma readings at the outer wall of the vessel at the precise location of the film after the source is propelled into the hollow tube. The reading can be made with any suitable gamma-survey instrument, such as a Victoreen Model 592B.

To calculate approximate exposure time, refer to Table III and locate the type of film being used and the desired film density. The table indicates the total amount of radiation required to expose the film to that density. For example, suppose a reading taken at the wall of the vessel indicates a radiation level of $3.87 \times 10^{-5}$ C/kg (150 mR/h). DuPont NDT 75 film is used, and the desired density is 1.5. From Table III, we see that a total of $710 \frac{\text{mR}}{150 \text{mR}} = 4.7$ h.

<table>
<thead>
<tr>
<th>TABLE III. Total Amount of $^{60}\text{Co}$ Radiation (in roentgens$^2$) Required to Yield Various Film Densities</th>
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<tbody>
<tr>
<td>Density</td>
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<tr>
<td>---</td>
</tr>
<tr>
<td>GAF C</td>
</tr>
<tr>
<td>DuPont 75</td>
</tr>
<tr>
<td>GAF A</td>
</tr>
<tr>
<td>EKC AA</td>
</tr>
<tr>
<td>DuPont 55</td>
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<tr>
<td>DuPont 55</td>
</tr>
<tr>
<td>GAF B</td>
</tr>
<tr>
<td>EKC M</td>
</tr>
<tr>
<td>GAF HD</td>
</tr>
<tr>
<td>DuPont 45</td>
</tr>
<tr>
<td>EKC R</td>
</tr>
</tbody>
</table>

$^2$Conversion factor: 1 roentgen $= 2.58 \times 10^{-4}$ C/kg.

To verify that the calculated exposure is correct, an extra (test) film should be placed behind the film that is in place. After about two-thirds of the calculated exposure time has elapsed, retract the source to its original container, remove the test film carefully so as not to disturb the other film, and process it. If the processed-film density seems low, lower the source to its original position and continue the exposure to the calculated time. If the film density is proper, the original film may be removed for processing.

C. Double-wall Radiography

In the radiography of refractory-lined piping to obtain the bore contour, a collimated beam of radiation is directed at one side of the pipe and film is secured at the opposite side, 180° from the source side. Figure 15 is a schematic diagram showing the arrangement used for radiography of piping.
Figure 16 shows the collimated source in position to generate a radiograph. Radiography is best performed during a plant shutdown period, after the piping has cooled. Piping can be radiographed at elevated temperatures [up to 260°C (500°F)] when the plant is in operation, if insulation is wrapped around the pipe to protect the film and film cassette from heat.

![Diagram of Radiographing Refractory-lined Piping](image1.png)

**Fig. 15**

![Photograph of Collimator](image2.png)

**Fig. 16.** Photograph of Collimator in Position to Generate Radiograph

The amount of insulation required depends on the surface temperature of the piping to be tested. The amount of insulation is adequate when the surface against which the film is to be placed is just warm to the touch. However, this method is not recommended because it increases the object-to-film distance by several centimeters and consequently degrades the image on the film. Vibrations in the system may also degrade the quality of the radiographic image, and may make it difficult to place the film at the desired location and keep it in place for the duration of the exposure.
Source-to-film distance may vary, depending on the diameter of the pipe and the area being exposed. Typically, the source-to-film distance may range from 1.2 to 1.8 m (4 to 6 ft). Exposure time is calculated and verified as described above for single-wall radiography.

D. Conclusions and Recommendations

Gamma radiography with $^{60}$Co has been shown to be a useful method to inspect refractory-lined vessels and piping. We have demonstrated that gamma radiography is capable of:

1. Imaging anchor orientations.

2. Recording density changes in the refractory caused by voids or differences in thickness or materials. Crack images ≥1.27 mm (0.05 in.) wide were discernible through nominally 23 cm (9 in.) of refractory. Void images as small as 6.3 mm (0.125 in.) can be seen through about 46 cm (18 in.) of refractory.

3. Imaging thin-walled coolant tubes. Thin-walled water-coolant tubes about 3.76 cm (1.5 in.) in diameter can be seen through nominally 46 cm (18 in.) of refractory.

4. Inspecting bore contour in refractory-lined piping.

5. Inspecting for proper installation of air-lift lines.

6. Showing air-lift-line blockage or damage.

7. Determining erosion rate of refractory.

Continued use of gamma radiography in coal-conversion systems may stimulate wider applications of the method that have been discussed.

Personnel at present and future coal-conversion plants should consider the application of gamma radiography to critical areas where refractory erosion may occur.
APPENDIX

Supplementary Information Related to Radioisotopic Sources

1. Radiographic Sources

   a. Curie

   The curie is a measure of the disintegration rate of a source:
   \[ 1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq} = 3.7 \times 10^{10} \text{ disintegrations per second.} \]

   b. Half-life

   The half-life, \( T \), of a given radioisotope is the length of time required for the activity to decay to one-half its initial strength. Because any radioactive isotope decays exponentially, it will require a definite time to fall to any given fraction of its initial strength. The manufacturer furnishes decay curves with every source purchased. Figure 17 is a decay chart for \( ^{60}\text{Co} \).

   c. Half-value Layer

   The half-value layer (hvl) is the thickness of a material that transmits 50% of the radiation incident upon it. Table II shows the half-value layers of some materials that are common in coal-conversion systems.

   d. Gamma-ray Energy

   The energy of gamma rays, expressed in thousands of electron volts (keV) or millions of electron volts (MeV), corresponds to that of the maximum-energy, or hardest, X-rays generated by an electronic X-ray tube energized at the stated potential. Since most of the X-rays emitted by a tube are at about 40% of the maximum energy, gamma rays show characteristics similar to X-rays of about twice the stated energy. Thus, the penetrating ability of gamma rays from \( ^{60}\text{Co} \), with energies of 1.17 and 1.33 MeV, is similar to that of X-rays from a 3-MeV X-ray generator.

e. **Specific Activity**

The specific activity of an isotopic source, usually measured in curies per gram of source material, is of importance to radiographers in two ways. First, a high specific activity indicates that a source of a given strength will be of smaller physical size and thus will tend to yield sharper radiographs. Second, less self-absorption of radiation will take place in a small source.

f. **Roentgen**

The roentgen (R), a unit of radiation intensity, is defined as that quantity of radiation for which the associated corpuscular emission produces, in 1 cm$^3$ of dry air at 0°C and 760 mm pressure, ions carrying one electrostatic unit of electricity of either sign.

g. **Gamma-ray Intensity**

Gamma-ray intensity is measured in roentgen per hour (R/h). A useful output number to associate with a radioactive source is (R/h)/Ci at a distance of 1 m (RHM/curie), a measure of radiation emission over a given period of time at a fixed distance. The activity (amount of radioactive material) of a gamma-ray source determines the intensity of its radiation.

2. **Fundamentals of Radiography**

To be examined by radiography, an object must be placed in the path of an X-ray (or gamma-ray) beam, and the intensities of the radiation passing through different parts of the specimen must be compared. The most common method for accomplishing this is to let the ray strike a recording medium, such as a photographic film, so that the blackening of the film after processing bears some relation to the radiation intensities. The resultant film is called a radiograph.

The image on the film is formed by X or gamma rays traveling in straight lines from the source through the object to the film. Figure 18 is a schematic diagram showing the fundamentals of a radiographic exposure. This geometric image formation is similar to shadow formation with visible light, and the sharpness of the image on the film depends on the area of the radiation source and on the source-to-film distance. A small-diameter source, i.e., a small-diameter X-ray tube focus or a small-dimensioned gamma-ray source, will produce sharp images; the important dimensions are the effective length and breadth of the focus, measured in a plane parallel to the plane of the film.
It has been demonstrated that, from an image-sharpness point of view, a large-area X-ray or gamma-ray focus can be compensated for by using a longer source-to-film distance. However, the intensity of the radiation at the plane of the recording media (film) varies inversely as the square of the distance between the source of radiation and the film. This is known as the inverse-square law. The inverse-square law can be expressed algebraically as

\[
\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}
\]

where \(I_1\) and \(I_2\) are the intensities at the distances \(D_1\) and \(D_2\), respectively. As the distance is increased, the exposure time that the film requires to produce a given effect increases rapidly. If the distance is doubled, four times the exposure time is necessary, and the exposure time may become too long to be practical.

3. Radiation Safety

The degree of safety with which a radiation device can be used depends upon the intelligence and judgment of the person who uses it. If appropriate precautions are taken, radioactive materials used in industrial radiography can be used as safely as toxic materials or electricity, which are common to industrial processes. The primary potential hazard from radiographic sources comes from exposure of personnel to radiation emitted by the sources. Gamma
radiation, like electricity, is to be respected more than feared. The three basic principles involved in controlling exposure of the body to gamma radiation are time, distance, and shielding.

a. **Time**

The total radiation exposure received by an individual in a field of radiation depends upon the length of time he stays there. A person remaining in a given field of radiation for 5 min would receive only one-half as much exposure as he would in 10 min.

b. **Distance**

The farther from a radiographic source a person can work, the lower will be his exposure for any given period of time. The exposure rate from a radioactive source decreases with distance in the same manner that the intensity of light decreases as a person moves farther from the source of light; i.e., the exposure rate varies inversely with the square of the distance from the source (inverse-square law, as shown previously).

c. **Shielding**

The use of shielding materials provides an excellent means for controlling personnel exposure while performing radiography. Materials commonly used to shield gamma radiation are concrete, lead, iron, and steel. Adequate shielding will probably not be available during exposures in field operations, because of the great amounts that would be necessary. To compensate for this, an area should be roped off around the location of the radioactive source, and personnel should be prohibited from entering this area except to put the source in position or return it to its container. Radiation warning signs should be posted to warn personnel to stay out of the area. The radiation level outside the roped-off area should not exceed $5.16 \times 10^{-7}$ C/kg-h (2 mR/h).

4. **Measuring and Monitoring Devices**

Safe operating conditions must be maintained while radiographs are generated in the field. The operator using a radioactive source should therefore be familiar with radiation-measuring and -monitoring devices.

Three general types of radiation-monitoring devices are used for field radiography. One type consists of a small penlike ionization chamber. Given an initial electrostatic charge, it discharges in proportion to the amount of radiation received. Direct-reading chambers (dosimeters) indicate, on an electrometer indicator in the chamber, the amount of radiation that has been received.
A second type of radiation monitor uses a large ionization chamber in conjunction with an electronic rate meter. This instrument reads the radiation intensity being received at a given location at the specific time that the instrument is in operation, independent of the time of exposure. These instruments (gamma-survey meters) are read by the deflection on a meter, which is calibrated directly in milliroentgens per hour. The gamma-survey meter is most useful for posting the areas of radiation hazard and for determining the minimum safe distance between personnel and the exposure area.

A third type of radiation-monitoring device is the film badge. This consists of a small film holder equipped with thin filters for insertion of special film sensitive to X and gamma radiation. After a period of time (often a month), the films are processed and the resultant radiographic film density through the various thicknesses of filter is read with a densitometer. By comparing the resultant density on the film, an individual can determine the amount of radiation he has received.

The operator of the exposure device and all personnel in the exposure area must wear film badges and dosimeters, and a properly calibrated gamma survey meter must be readily available.
ACKNOWLEDGMENTS

I wish to acknowledge the close cooperation of Mr. John Miles and Mr. John Byron of Phillips Petroleum (Bi-Gas), Mr. Bob Adams of Battelle, Mr. Clark Abrams of Gamma Field Radiographic Facility, and Mr. Robert Vogt, formerly of ANL. I also wish to thank Drs. K. J. Reimann and W. A. Ellingson for valuable discussions and help in the preparation of this report.

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