

(R) PENETRATING RADIATION INSPECTION

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

1. **Scope**—The purpose of this SAE Information Report is to provide basic information on penetrating radiation, as applied in the field of nondestructive testing, and to supply the user with sufficient information so that he may decide whether penetrating radiation methods apply to his particular inspection need. Detailed information references are listed in Section 2.

2. **References**

2.1 **Applicable Publications**—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 ASTM PUBLICATIONS—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103

ASTM E 94—Recommended Practice for Radiographic Testing

ASTM E 545—Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing

2.2 **Related Publications**—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 ASM PUBLICATION—ATTN: MSC/Book Order, ASM International, PO Box 473, Novelt, OH 44072-9901.

Metals Handbook, Vol. 17, 1989, pp. 295–357.

2.2.2 ASME PUBLICATION—Available from ASME, 345 East 47 Street, New York, NY 10017-2330.

"ASME Boiler and Pressure Vessel Code."

2.2.3 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

ASTM E 142, "Controlling Quality of Radiographic Testing."

ASTM E 545 "Standard Method for Determining Image Quality in Thermal Neutron Radiographic Testing."

ASTM E 748 "Standard Practice for Thermal Neutron Radiography of Materials."

H. Berger, ed., "Practical Applications of Neutron Radiography and Gaging," ASTM STP 586.

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2.2.4 OTHER PUBLICATIONS

- Nondestructive Testing Handbook, Vol. 3, Radiography and Radiographic Testing, 1985, American Society for Nondestructive Testing, Columbus, OH 43228
- Tool and Manufacturing Engineers Handbook, Vol. 4, Quality Control Assembly, 1987, Society of Manufacturing Engineers, Dearborn, MI 48121
- "Radiography in Modern Industry." Eastman Kodak Co., Rochester, NY, 1969.
- John R. Bradford, ed., "Radioisotopes in Industry." 1953.
- R. C. McMaster, ed., Nondestructive Testing Handbook, Vol. I, Section 13–27, 1959. American Society of Nondestructive Testing, Columbus, OH 43321.
- H. Berger, Neutron Radiography. New York: American Elsevier Publishing Co., 1965.
- W. J. McGonnagle, Nondestructive Testing. New York: McGraw-Hill Book Co., 1961.
- R. Halmshaw, ed., Industrial Radiology Techniques. New York: American Elsevier Publishing Co., 1971.
- E. T. Clarke, "Gamma Radiography of Light Metals." Nondestructive Testing, Vol. 16, May-June 1958, p. 265.
- "Qualification and Certification of Personnel." Recommended Practice No. SNT-TC-1A, Supplement A (Radiography), American Society for Nondestructive Testing, Columbus, OH 43328.
- Justin G. Schneeman, Industrial X-Ray Interpretation. Evanston, IL: Intex Publishing Co., 1968.
- "Radiographic Testing." Programmed Instruction Handbook PI-4–6, Convair Div., General Dynamics Corp., 1967.
- AMS 2635 C "Radiographic Inspection." July 15, 1981.
- "Military Standard Inspection—Radiographic." MIL-STD-453, U.S. Department of Defense.
- M. R. Hawkesworth, ed., "Radiography with Neutrons," British Nuclear Energy Society, London, 1975." Neutron Radiography Issue, Atomic Energy Review, Vol. 15, No. 2, International Atomic Energy Agency, Vienna, 1977.

3. **General**—Penetrating radiation is a versatile nondestructive test method used in modern industry. The use of penetrating x-rays, gamma rays, thermal neutrons, and other forms of radiation which do not affect the material being inspected, provide the basic information by which soundness can be determined. Radiography provides a permanent record on film of internal conditions. Fluoroscopy differs from radiography in that the radiation image is projected on a fluorescent screen or other readout monitor and is often observed visually in real time rather than recorded on a film. Systems are available that produce digitally reconstructed, photographic, or magnetically recorded displays. Penetrating radiation enables industry to monitor a variety of products for a number of types of imperfections. Objects inspected range in size from microminiature electronic parts to very large components in a wide range of manufactured forms (for example, castings, weldments, assemblies).
4. **Principles**—X-rays, gamma rays, and neutrons possess the capability of penetrating materials, even those that are opaque to light. In passing through matter, some of these rays are absorbed or scattered. Materials absorb x-rays and gamma rays in proportion to their mass. Neutron absorption, on the other hand, is not related proportionally to atomic number or mass; neighboring elements can differ in neutron absorption by factors of 100 or more. Differential absorption of the radiant energy passing through the object due to the presence of voids, discontinuities, or density variations caused by inhomogeneity or internal construction is recorded on radiographic film or observed directly by fluoroscopic methods. With acceptable conditions of technology and equipment, it is generally agreed that discontinuities can be detected which present to the axis of radiation a minimum dimension of 1 to 2% of the thickness of the object undergoing radiographic examination, or 2 to 6% for fluoroscopic examination. Two-dimensional imperfections, such as cracks and cold shuts, are not detectable unless they present an effective thickness difference of the above magnitude, or greater, and are in appropriate alignment with the beam of radiation.

5. Procedure

5.1 Radiographic Film Technique—A radiographic film is a photographic record produced by the passage of x-rays, gamma rays, or neutrons through an object onto a film. When film is exposed to a radiation source or light, an invisible change is produced in the film emulsion. The areas so exposed become dark when the film is immersed in a developing solution; the amount of darkening depends upon the degree of exposure. Image formation is usually enhanced through use of thin metal screens in intimate contact with the film. Lead screens are used in x-ray exposures made with energy above 100 kV and in gamma ray exposures. Screens are necessary for film detection of thermal neutrons. Gadolinium metal screens are normally used for direct-exposure techniques and indium metal screens are normally used for indirect-exposure techniques. The developing, fixing, and washing of exposed film may be done either manually or in an automatic film processor. The exposed, processed, and dried radiographic film is examined under transmitted light. Interpretation of the image is performed in accordance with established codes, specifications, or acceptance criteria.

The finished radiograph should be viewed under conditions which provide for the best visualization of detail combined with maximum comfort and minimum fatigue for the observer. A high-intensity illuminator with adjustable intensity is almost a necessity for optimum radiographic observation and interpretation. Penetrameters are used to indicate the image quality which exists in a radiograph. The type generally used in the United States is a small rectangular plate of the same material as the object being x-rayed. It is uniform in thickness (usually 2% of the object thickness) and has holes drilled through it. ASTM specifies hole diameters 1, 2, and 4 times the thickness of the penetrometer. Step, wire, and bead penetrameters are also used. (See ASTM E 94.) For neutron radiography, image quality indicators provide a measure of the relative exposure due to gamma rays, higher energy neutrons, and scattered neutrons. Additional image quality indicators are suggested to provide measures of contrast and resolution capability. (See ASTM E 545.)

- 5.1.1 **ADVANTAGES**—Film radiography provides a permanent, visible record of the internal condition of the subject. Preservation of films is a common practice in industry.
- 5.1.2 **DISADVANTAGES**—High cost is the chief objection to film radiography. One-half of the average inspection cost may be the radiographic film cost. X-ray paper products reduce this disadvantage when maximum performance capability is not required.

Inspection results are not available until radiographic film has been exposed, processed, and interpreted.

5.2 Fluoroscopic Inspection Technique—Fluoroscopy is the process of examining an object by direct or indirect observation of the fluorescence of a screen caused by radiation transmitted through an object. The arrangement of the x-ray source, object, and imaging plane is identical to that used in radiography. The fluorescent screen, image intensifier tube, television camera, and similar electronic imaging devices convert x-ray to visible light for further signal processing, operator interpretation, and recording.

- 5.2.1 **ADVANTAGES**—Production line inspection systems are available. These can result in low cost per part inspected and can meet the inspection requirements of high-volume production. Real-time image enhancement and interpretation are available in systems using television imaging.
- 5.2.2 **DISADVANTAGES**—The sensitivity of the fluoroscopic process is not usually as great as that of radiography, 2 to 6% being routine. The additional cost of producing a permanent record of the examination may be a disadvantage. For systems employing television imaging, however, magnetic recording can be used, photographs may be taken of the television image, or digital processing can be used for imaging and interpretation.

6. Application—The ability of high energy radiation to penetrate all engineering materials and the differential rates of absorption for different materials are responsible for the extensive use of this nondestructive inspection technique throughout industry. Accordingly, penetrating radiation inspection methods are extensively used for flaw detection in the following areas:

- 6.1 Castings**—The widespread use of penetrating radiation methods for the inspection of castings results from the fact that most of the flaws and discontinuities inherent in ferrous and nonferrous castings can be readily detected by this inspection medium. Shrinkage, gas porosity, inclusions, hot tears, cracks, cold shuts, core shifts, and major surface irregularities may be detectable by radiographic or fluoroscopic inspection techniques. In addition, the following discontinuities which are peculiar to light metal (aluminum and magnesium) castings are detectable: gas holes, dross inclusions, segregation, microshrinkage, hydrogen porosity, microporosity, shrinkage, sponge, cold shuts, and other discontinuities common to light metal castings.
- 6.2 Weldments**—Penetrating radiation inspection of weldments is a widely accepted procedure for the detection of internal discontinuities. It is used in the establishment of welding procedures to qualify welders and especially to control quality of welded joints in finished products. The following imperfections or discontinuities are detectable by radiography: porosity, cracks, incomplete penetration and fusion, inclusions, and other discontinuities common in welded joints.
- 6.3 Finished Assemblies**—Penetrating radiation techniques are applicable to the inspection of fabricated assemblies relative to placement of internal components, such as electronic devices, mufflers, fuel tanks, bonded honeycomb, and tires. Electrical connections as well as the position of bolts and nuts in finished enclosures are frequently checked by radiography. Neutron radiography of assemblies provides a capability to verify proper placement of hydrogen-containing materials in metal assemblies. By this method rubber O-Rings, plastic parts, propellants, fluid levels, and similar materials can be visualized even when these objects are inside metallic containers.
- 6.4 Miscellaneous Applications**—Occasional use is made of radiographic techniques in the inspection of forgings, powder metal parts, and of nonmetallic materials such as plastic, rubber, ceramic, and solid propellant. The limited use of this inspection medium for forgings is explained by the fact that forging defects are smaller in size and unsuitably oriented for reliable detection by radiography.
- 7. Equipment**—There are a number of factors which affect the use of penetrating radiation to varying extents. These factors can be grouped into three general categories as follows:
- a. Source of radiation
 - b. Object or material to be examined
 - c. Detecting or recording medium.

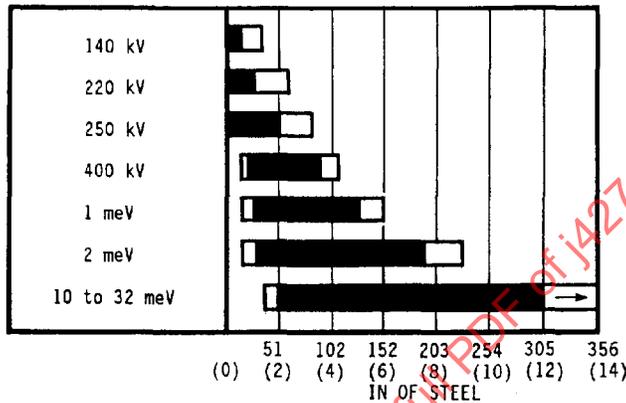
Sources for neutron radiography include nuclear reactors, accelerators, and radioactive isotopes. These sources can be moved (in a truck, for example) but most neutron radiographic inspection is done by bringing the inspection object to the source. Radiation sources for other types of radiography involve either x-ray generators or one of several radio isotopes. X-rays are produced when high-velocity electrons impinge upon target atoms. The energy of the x-radiation produced is a function of the velocity of the impinged electrons, which in turn is dependent upon the applied anode voltage (kV or MeV). The practical thickness range of steel which can be inspected by x-ray units is proportional to their radiation energy, as shown in Figure 1. The usefulness of Figure 1 can be extended to other materials by referring to Table 1, which gives equivalence factors for various other materials as compared to steel.

Radiographic isotopes emit radiation at discrete energy levels. The approximate practical thickness range of the most commonly used radioisotopes for steel is included in Figure 2. The energy level of the gamma radiation for the two most commonly used isotopes determines the equivalence factor for materials other than steel (included in Figure 2). Table 1 can be utilized to approximate these equivalence factors by averaging the energy values for a given source and using the closest energy level column in the table.

Other factors such as economics, flexibility, sensitivity, maintenance costs, and portability must of necessity be considered when deciding the type of unit to be used.

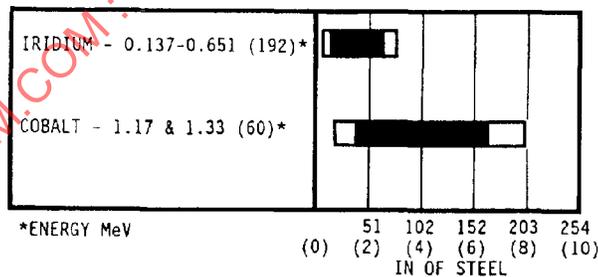
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Generally, x-ray film is used as the detecting medium. Various types of film are commercially available. These differ in speed, grain, and contrast. The selection of a film is interrelated with the type and energy of the radiation, and the material and thickness of the object to be inspected. Factors such as sensitivity required and exposure time are also considerations. Industrial x-ray paper may be used as a detecting medium. Paper supported emulsions offer several advantages: lower material cost, increased processing speed, darkroom simplicity, and space savings. Consideration should be given to this process if maximum sensitivity and long periods of radiographic print storage are not required. Other detecting media are available, such as instant process film and xerographic processes.



The shaded portions of the bar represent thickness where 1% sensitivity is obtained.
 The unshaded portion at Bar ends represent 2% sensitivity.
 NOTE—Dimensions are mm (inch)

FIGURE 1—APPROXIMATE PRACTICAL THICKNESS RANGES OF STEEL FOR VARIOUS X-RAY KILOVOLTAGES



The shaded portions of the bar represent thickness where 1% sensitivity is obtained.
 The unshaded portion at Bar ends represent 2% sensitivity.
 NOTE—Dimensions are mm (inch)

FIGURE 2—APPROXIMATE PRACTICAL THICKNESS OF STEEL FOR VARIOUS RADIOACTIVE ISOTOPE SOURCES

Fluoroscopic systems are available for instantaneous radiographic inspections. The sensitivity of this type of inspecting medium is somewhat less than the photographic method.

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8. **Protection**—Personnel protection from all forms of radiation is an essential requirement in the use of penetrating radiation. It is a fact that scattered as well as direct rays have a biological and physical effect on all living matter. It is recommended (and is generally a legal requirement) that all persons operating or working near any source of radiation keep a record of the radiation dosage received weekly and at no time exceed the limits allowed by the Nuclear Regulatory Commission, or licensing state.

9. **Notes**

9.1 **Marginal Indicia**—The change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

TABLE 1—APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS FOR SEVERAL METALS
IN RELATION TO STEEL ⁽¹⁾ (ADAPTED FROM ASTM E 94)

Metal ⁽²⁾	140 kV	220 kV	250 kV	400 kV	1 MeV	2 Mev
Aluminum (2.7)	0.083	0.24	0.24	--	--	--
Magnesium (1.7)	0.05	0.08	0.08	--	--	--
Steel (7.8)	1.0	1.0	1.0	1.0	1.0	1.0
Stainless (7.9)	1.0	1.0	1.0	1.0	1.0	1.0
Copper (8.9)	1.8	1.4	1.4	1.4	--	--
Zinc (7.1)	--	1.3	1.3	1.3	--	--
Brass (8.4)	--	1.3	1.3	1.3	1.2	--
Lead (11.3)	--	11.0	--	--	5.0	2.5

1. To determine upper practical limit for materials listed other than steel, divide the value given for steel by the proper equivalence factor. Table 1 may be extended to apply to radioisotopes by taking the average of the energy values given in Figure 2, and using the nearest size x-ray unit in the table.
2. Density is given in parentheses.

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NONDESTRUCTIVE TEST METHODS