



Standard Reference Radiographs for Steel Castings Up to 2 in. (50.8 mm) in Thickness¹

This standard is issued under the fixed designation E446; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 These reference radiographs² illustrate various categories, types, and severity levels of discontinuities occurring in steel castings that have section thicknesses up to 2 in. (50.8 mm) (see [Note 2](#)). The reference radiograph films are an adjunct to this standard and must be purchased separately from ASTM International, if needed (see [2.2](#)). Categories and severity levels for each discontinuity type represented by these reference radiographs are described in [1.3](#).

NOTE 1—The basis of application for these reference radiographs requires a prior purchaser supplier agreement of radiographic examination attributes and classification criterion as described in Sections [4](#), [6](#), and [7](#) of this standard.

NOTE 2—Reference radiographs previously used for this thickness range carried the designation E71, but included a now rarely used gamma source, that is, radium. The current document is also updated by inclusion of several recognized *shrinkage* or *C* categories and by elimination of the crack and hot tear categories except for one example of each of these discontinuity types. Reference radiographs for thicker sections may be found in Reference Radiograph standards [E186](#) and [E280](#). Reference Radiograph standards E446 and [E186](#) provide some overlap of severity levels for similar discontinuity categories within the same energy level range (see [4.2](#), [5.1](#), and [6.3](#)).

1.2 These film reference radiographs are not intended to illustrate the types and degrees of discontinuities found in steel castings when performing digital radiography. If performing digital radiography of steel castings up to 2 in. (50.8 mm) in thickness, refer to Digital Reference Image Standard [E2868](#).

1.3 These reference radiographs consist of three separate volumes (see [Note 3](#)) as follows: (I) medium voltage (nominal 250-kV) X-rays. (II) 1-MV X-rays and Iridium-192 radiation, and (III) 2-MV to 4-MV X-rays and cobalt-60 radiation. Unless otherwise specified in a purchaser supplier agreement (see [1.1](#)), each volume is for comparison only with production radiographs produced with radiation energy levels within the thickness range covered by this standard. Each volume consists of

six categories of graded discontinuities of increasing severity level and four categories of ungraded discontinuities. Reference radiographs containing ungraded discontinuities are provided as a guide for recognition of a specific casting discontinuity type where severity levels are not needed. Following is a list of discontinuity categories, types and severity levels for the adjunct reference radiographs of this standard:

- 1.3.1 *Category A*—Gas porosity; severity levels 1 through 5.
- 1.3.2 *Category B*—Sand and slag inclusions; severity levels 1 through 5.
- 1.3.3 *Category C*—Shrinkage; 4 types:
 - 1.3.3.1 *Ca*—linear shrinkage—Severity levels 1 through 5.
 - 1.3.3.2 *Cb*—feathery shrinkage—Severity levels 1 through 5.
 - 1.3.3.3 *Cc*—sponge shrinkage—Severity levels 1 through 5.
 - 1.3.3.4 *Cd*—combinations of linear, feathery and sponge shrinkage—Severity levels 1 through 5.
- 1.3.4 *Category D*—Crack; 1 illustration.
- 1.3.5 *Category E*—Hot tear; 1 illustration.
- 1.3.6 *Category F*—Insert; 1 illustration.
- 1.3.7 *Category G*—Mottling; 1 illustration.

NOTE 3—The reference radiographs consist of the following:
Volume I: Medium Voltage (nominal 250 kVp) X-ray Reference Radiographs—set of 34 illustrations (nominal 5 by 7 in.) in a 15 by 17-in. ring binder.

Volume II: 1-MV X-rays and Iridium-192 Reference Radiographs—Set of 34 illustrations (nominal 5 by 7 in.) in a 15 by 17-in. ring binder.

Volume III: 2-MV to 4-MV X-rays and Cobalt-60 Reference Radiographs—Set of 34 illustrations (nominal 5 by 7 in.) in a 15 by 17-in. ring binder.

NOTE 4—Although Category G—Mottling is listed for all three volumes, the appearance of mottling is dependent on the level of radiation energy. Mottling appears reasonably prominent in Volume I; however, because of the higher radiation energy levels mottling may not be apparent in Volume II nor Volume III.

1.4 From time to time, there may be minor changes to the process for manufacturing of the reference radiograph adjunct materials. These changes could include changes in the films or processing chemicals used, changes in the dies or printing for the cardboard mats, etc.; however, in all cases, these changes are reviewed by the Illustration Monitoring Subcommittee and all reference radiographs are reviewed against a fixed prototype image to ensure that there are no changes to the acceptance level represented by the reference radiographs. Therefore, the

¹ These reference radiographs are under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and are the direct responsibility of Subcommittee E07.02 on Reference Radiological Images.

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² For ASME Boiler and Pressure Vessel Code applications see related Reference Radiographs SE-446 in Section V of that Code.

adjunct reference radiographs remain valid for use with this standard regardless of the date of production or the revision level of the text standard.

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:³

E94 Guide for Radiographic Examination

E186 Reference Radiographs for Heavy-Walled (2 to 4½-in. (50.8 to 114-mm)) Steel Castings

E242 Reference Radiographs for Appearances of Radiographic Images as Certain Parameters are Changed

E280 Reference Radiographs for Heavy-Walled (4½ to 12-in. (114 to 305-mm)) Steel Castings

E1316 Terminology for Nondestructive Examinations

E2868 Digital Reference Images for Steel Castings up to 2 in. (50.8 mm) in Thickness

2.2 ASTM Adjuncts:⁴

Reference Radiographs for Steel Castings Up to 2 in. (50.8 mm) in Thickness:

Volume I, Medium Voltage (Nominal 250 kVp) X-Rays⁵

Volume II, 1-MV X-Rays and Iridium-192⁶

Volume III, 2-MV to 4-MV X-Rays and Cobalt-60⁷

3. Terminology

3.1 *Definitions*—For definitions of terms relating to radiographic examination, see Terminology **E1316**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *production radiograph*—a radiograph under review for compliance with this standard.

3.2.2 *discontinuity type*—a specific discontinuity characterized by its cause and appearance. For example: linear shrinkage is a specific discontinuity type.

3.2.3 *discontinuity category*—a nomenclature system used for grouping discontinuity types. For example: linear shrinkage is assigned category “Ca” where “C” represents the general shrinkage category and “a” represents the specific linear shrinkage discontinuity type.

3.2.4 *discontinuity severity level*—a relative rank in terms of “quantity, size and distribution” of a collection of discontinuities where “1” is the least and “5” is the greatest “quantity, size

and distribution” present on the reference radiograph. Example: a severity level of “1” is more restrictive (requires a higher level of workmanship fabrication quality) than a severity level of “2”.

3.2.5 *discontinuity class*—an assigned workmanship fabrication quality rating characterized by a discontinuity type, category and severity level. For example: “Ca 2” is a discontinuity class comprised of linear shrinkage with a severity level of “2”.

3.2.6 *classification specification*—a set of user defined acceptance criterion that prescribes the radiographic workmanship discontinuity class requirements for a specified user casting service application (see Sections 6 and 7).

3.2.7 *graded illustration*—a category of discontinuity that is assigned a severity level.

3.2.8 *ungraded illustration*—a category of discontinuity without an assigned severity level.

3.2.9 *prorating*—assignment of quantity, size and distribution on a production radiograph in proportion to a similar size area of a reference radiograph. For example: a production radiograph covers an area that is smaller than the unit area of a reference radiograph and the extent of discontinuity on the applicable reference radiograph is reduced proportionately.

4. Significance and Use

4.1 Graded reference radiographs are intended to provide a guide enabling recognition of specific casting discontinuity types and relative severity levels that may be encountered during typical fabrication processes. Reference radiographs containing ungraded discontinuities are provided as a guide for recognition of a specific casting discontinuity type where severity levels are not needed. These reference radiographs are intended as a basis from which manufacturers and purchasers may, by mutual agreement, select particular discontinuity classes to serve as standards representing minimum levels of acceptability (see Sections 6 and 7).

4.2 Reference radiographs represented by this standard may be used, as agreed upon in a purchaser supplier agreement, for energy levels, thicknesses or both outside the range of this standard when determined applicable for the casting service application. Severity levels of similar discontinuity categories and energy level range of **E186** reference radiographs may alternatively be used, as determined appropriate for the casting service application, if so agreed upon in the purchaser supplier agreement (see **Note 2** and **5.1**).

4.3 Procedures for evaluation of production radiographs using applicable reference radiographs of this standard are prescribed in Section 8; however, there may be manufacturing-purchaser issues involving specific casting service applications where it may be appropriate to modify or alter such requirements. Where such modifications may be appropriate for the casting application, all such changes shall be specifically called-out in the purchaser supplier agreement or contractual document. Section 9 addresses purchaser supplier requisites for where weld repairs may be required.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

⁴ Available from ASTM Headquarters.

⁵ Order **RRE044601**.

⁶ Order **RRE044602**.

⁷ Order **RRE044603**.

5. Method of Preparation

5.1 The original radiographs used to prepare the adjunct reference radiographs were produced on ASTM Class I or II film systems by the respective use of 250-kV X-ray, Iridium-192 and Cobalt-60 sources of radiation. The original radiographs were made with penetrometer sensitivity as determined by ASTM penetrameters (see Guide E94) of 2-2T. The adjunct reference radiographs are reproductions prepared to an optical density of 2.00 to 2.25 and have substantially retained the contrast of the original radiographs. In preparing these reference radiographs, the objective was to obtain progressively graduated severity levels for each graded discontinuity category of this standard. Additionally, some overlap of severity levels may occur for discontinuity categories of this standard and similar discontinuity categories of E186 reference radiographs within the same energy level range. For example, aggregate gas porosity severity level 5 of this standard exceeds aggregate gas porosity severity level 1 of Reference Radiograph E186 (see 6.3).

5.2 *Film Deterioration*—Radiographic films are subject to wear and tear from handling and use. The extent to which the image deteriorates over time is a function of storage conditions, care in handling and amount of use. Reference radiograph films are no exception and may exhibit a loss in image quality over time. The radiographs should therefore be periodically examined for signs of wear and tear, including scratches, abrasions, stains, and so forth. Any reference radiographs which show signs of excessive wear and tear which could influence the interpretation and use of the radiographs should be replaced.

6. Determination of Radiographic Classification

6.1 For purposes of evaluation of castings, a determination must be made of the radiographic discontinuity classifications to be assigned to individual castings or specific areas of castings. The determination of the applicable radiographic discontinuity classification shall be based on an evaluation of the casting applications, design, and service requirements. In these evaluations, consideration shall be given to such factors as pressure, temperature, section thickness, applicable design safety factor (preferably based on stress analysis), vibration, shock, resistance to corrosion, involvement of penetrating radiations or radiation products, and involvement of dangerous gases or liquids.

6.2 For each individual casting or specific area of a casting to be radiographed, the discontinuity class must be clearly specified. For example, severity level 2 might be specified for linear shrinkage, Category Ca, and severity level 3 for gas porosity, Category A, since the latter are generally much less deleterious to tensile properties (see Section 7).

6.3 When determining discontinuity severity levels for individual castings spanning multiple thickness ranges outside the range of this standard, consideration should be given to the potential for overlapping severity levels as described in 4.2 and 5.1.

6.4 Production radiographs which are compared to reference radiographs should have an optical density in the area of

interest in accordance with Guide E94 and a specified minimum radiographic sensitivity (quality level) of 2% (2-2T). Other radiographic quality levels or optical densities may be designated, but then a corresponding change in severity level for each discontinuity category should be anticipated and hence specified.

7. Classification Specifications

7.1 The applicable radiographic discontinuity classification should be designated by the contracting agency in formal specifications or on drawings and in specific contracts or orders. The specifications, drawings, contracts, or order should also designate the sampling plan for the castings to be radiographed and the extent of radiographic coverage, radiographic practice to be followed (Guide E94), image quality desired (Note 5) as well as the severity of the acceptable discontinuity for the graded categories.

NOTE 5—For description of radiographic sensitivity or quality levels, see Guide E94 and Reference Radiographs E242.

8. Evaluation Procedure

8.1 Compare the production radiographs of the casting submitted for evaluation with the reference radiographs exposed at an equivalent energy range within the thickness range of this standard (unless otherwise specified—see Section 4).

8.2 When the severity level of discontinuities in the production radiograph being evaluated is equal to or less than the severity level in the specified reference radiograph, that part of the casting represented by the production radiograph shall be acceptable. If the production radiograph shows discontinuities of greater severity than the reference radiograph, that part of the casting shall be rejected.

8.3 A unit area on the production radiograph shall be evaluated to a unit area of like size on the reference radiograph. Any unit evaluation area that shares a discontinuity with an adjacent unit evaluation area shall meet the minimum unit area acceptability requirements within the combined unit area. When the unit area of interest of a production radiograph is less than the unit area of the applicable reference radiograph, such unit area of the production radiograph shall be prorated to the reference radiographic area.

8.4 When two or more categories of discontinuity are present in the same production radiograph, the predominating discontinuities, if unacceptable, shall govern without regard to the other categories of discontinuity and the casting rejected.

8.5 When two or more categories of discontinuity are present to an extent equal to the maximum permissible level as shown in the applicable standards for each category, then that part of the casting shall be judged unacceptable. When two or more categories of discontinuity are present in the same radiograph to an extent less than the maximum permissible level, as shown in the applicable standards for each category, the severity shall be evaluated by the overall aggregate condition. The aggregate condition is defined as the balance of quantity, size and distribution of the collection of discontinuities and shall not exceed the aggregate condition of the applicable reference radiograph.

8.6 Reference radiographs are provided showing a variety of shrinkage discontinuity types. Production radiographs showing shrinkage shall be judged by the most representative reference radiograph.

8.7 This standard does not specify limiting criteria for a single size of discontinuity, maximum number of discontinuities per unit area evaluated, specific dimensional spacing and/or alignment criterion between individual discontinuities or any other undefined discontinuity patterns. Unless otherwise specified by a purchaser supplier agreement (see Section 4), these discontinuity conditions on production radiographs shall be evaluated as aggregate conditions as defined in 8.5.

8.8 In general, there is no limit as to the extent of acceptable discontinuities in a casting, provided that no unit evaluation area throughout the casting contains discontinuities that exceed the severity of discontinuities in the applicable reference radiographs.

8.9 Reference radiographs in this standard do not illustrate elongated or “worm hole” type of gas discontinuities. When this condition occurs in a production radiograph, it shall be evaluated by comparison with the most representative reference radiograph.

8.9.1 When the exposing radiation source has been placed perpendicular to the length of the gas hole, evaluate the production radiograph with a shrinkage reference radiograph.

8.9.2 When the exposing radiation source has been placed diametrically or “into” the diameter of the gas hole, evaluate the production radiograph with a gas reference radiograph.

8.10 A diffraction mottling pattern can occur on films of parts and sections where the grain size is large enough to be an appreciable fraction of the material thickness (Note 6). If diffraction mottling is suspected, there are a number of ways to demonstrate its presence. The diffraction mottling pattern shown in these cases is dependent principally upon the crystal geometry and the orientation of the crystals to the incident radiation. Therefore, for a given specimen, any change in this orientation will affect the diffraction pattern dramatically. This can be accomplished by a slight, 1 to 5° tilt of the part, with respect to the radiation beam or simply by shifting the center

line of the radiation beam to a slightly different location from the first exposure. Indications from any porosity, shrinkage, or other discontinuity will move only slightly, while any mottling patterns present will change dramatically. If it is necessary or desirable to eliminate the mottling, the kV may be raised to reduce the amount of diffraction radiation. However, caution should be used so that the kV is not raised to the point that sensitivity is reduced excessively. If diffraction mottling is demonstrated to be present on a radiograph, this condition shall not be considered as prejudicial in evaluating the radiograph.

NOTE 6—Mottling is often associated with thin sections of austenitic steels, and copper base alloys such as copper nickel, tin bronzes, and nickel copper.

8.11 Hot tears and cracks exhibited on production radiographs may at times resemble linear type shrinkage. When doubt exists whether such indications are cracks or tears, or are linear shrinkage, all surfaces in the area of interest shall be ground and magnetic particle or liquid penetrant inspected as applicable. The extent and depth of grinding may require engineering judgment. If the indication does not appear on the surface, that indication shall be considered shrinkage.

8.12 The radiographic density of discontinuities in comparison with background density is a variable dependent on technical factors. It shall not be used as a criterion for acceptance or rejection in comparison with reference radiographs.

9. Weld Repair of Castings

9.1 When radiographic quality castings are repaired by welding, the reference radiographs to be used in the evaluation of the repaired sections must be specifically agreed upon between purchaser and supplier.

9.2 When casting discontinuities are removed for repairs, only the extent of discontinuity required to meet applicable reference standards need be removed.

10. Keywords

10.1 discontinuity classification criterion; gamma ray; reference radiographs; steel castings; x-ray

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