T9074-AS-GIB-010/271

NAVSEA Technical Publication

REQUIREMENTS FOR NONDESTRUCTIVE TESTING METHODS

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PUBLISHED BY DIRECTION OF COMMANDER, NAVAL SEA SYSTEMS COMMAND

30 APRIL 1997

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From: Commander, Naval Sea Systems Command

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Encl: (1) ACN Notice 1 of 16 Feb 99

Enclosure (1 incorporates change to NAVSEA T9074-AS-GIB-010/271.

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NAVSEA Technical Publication

REQUIREMENTS FOR NONDESTRUCTIVE TESTING METHODS

TO ALL HOLDERS OF NAVSEA T9074-AS-GIB-010/271

1. The following attached pages of T9074-AS-GIB-010/271 have been revised and supersede the pages listed.

New page	Date	Superseded page	Date
ACN-1 3	16 February 1999	Original 3	30 April 1997
ACN-1 4	16 February 1999	Original 4	30 April 1997
ACN-1 25	16 Februray 1999	Original 25	30 April 1997
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ACN-1 35	16 February 1999	Original 35	30 April 1997
ACN-1 36	16 February 1999	Original 36	30 April 1997

2. RETAIN THIS NOTICE AND INSERT BEFORE TABLE OF CONTENTS.

3. Holders of T9074-AS-GIB-010/271 will verify that page changes and additions indicated above have been entered. This notice page will be retained as a check sheet. This issuance, together with appended pages, is a separate publication. Each notice is to be retained by stocking points until the Technical Publication is completely revised or canceled.

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Continue on reverse side or add pages as needed.

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RECORD OF REVISIONS

REVISION NO.	DATE	ENTERED BY
0	30 April 1997	Complete Reprint Incorporated

LIST OF EFFECTIVE PAGES

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1. SCOPE

1.1 General. This document covers the requirements for conducting nondestructive tests (NDT) used in determining the presence of surface and internal discontinuities in metals. It also contains the minimum requirements necessary to qualify nondestructive test and inspection personnel, procedures, and nondestructive test equipment. This document does not contain acceptance criteria for nondestructive tests. This document does not cover all of the requirements for performing nondestructive tests in an underwater environment. Nondestructive tests in an underwater environment shall be performed as specified in NAVSEA S0600-AA-PRO-070.

1.1.1 Test areas. Areas to be tested shall be specified in the applicable drawings, specifications, contract or purchase order. Nondestructive test markings incorporated in drawings shall be in accordance with AWS A2.4.

1.1.2 Calibration. Since calibration procedures are self-contained in this document, the test instruments and standards contained herein are not included in Calibration Programs defined by ANSI/NSL Z540-1 with the exception of linear measuring tools such as mechanical calipers and micrometers.

1.2 Classification. This document covers the following types of test methods:

(a) Radiography (RT)
(b) Magnetic particle (MT)
(c) Liquid penetrant (PT)
(d) Ultrasonic (UT)
(e) Eddy current (ET)
(f) Visual inspection (VT)

1.3 Acceptance standards. The standards for acceptance shall be as specified in the applicable specification, contract, or order.

1.4 Time of inspection. Acceptance inspection shall be performed on an item in the final surface condition and final heat-treated condition, except as specified in 3.3.1.2, 3.3.1.3, 3.3.1.4, or in the applicable specification.

1.5 General definitions. The standard terminology for nondestructive examinations as described in ASTM E 1316 shall apply to this document, except as noted below and in the individual sections of this document.

1.5.1 Authorized representative of the Naval Sea Systems Command (NAVSEA). Unless otherwise specified, the Commander of a Naval Shipyard, the Supervisor of Shipbuilding, or their delegated representative.

1.5.2 Government inspector. Government official who is charged with the responsibility for assuring that the materials, processes, fabrication technique, and testing personnel meet specification and contractual requirements. In this regard, he or she may be as follows:

(a) For Government shipyards: The Shipyard Commander or his delegated representative.
(b) For commercial shipyards: The Supervisor of Shipbuilding or his delegated representative.
(c) For other organizations: The cognizant Government inspector, his representative or the representative of another Government agency designated by or through the cognizant Government inspector.
(d) For Forces Afloat: The squadron commander or his delegated representative.
(e) For Naval Repair Facilities: The commanding officer or his delegated representative.

1.5.3 Activity. All sites of an organization under the same quality assurance management and using the same quality assurance plan performing work to which this document is applicable.

1.5.4 Nominal thickness. That thickness specified on plans or drawings without application of any allowed tolerance.

1.5.5 Nondestructive test examiner. The examiner is the individual(s) to whom the activity assigns the responsibility and authority to examine and certify nondestructive test personnel to ensure that their personnel are competent and qualified to perform the applicable tests in conformance with contractual requirements. This is the individual to whom the activity assigns the responsibility of approving nondestructive test procedures and workmanship standards. The examiner is equivalent to the Level III in ASNT SNT-TC-1A.

1.5.6 Nondestructive test operator. The operator is equivalent to the Level I in ASNT SNT-TC-1A.

1.5.7 Nondestructive test inspector The inspector is equivalent to the Level II in ASNT SNT-TC-1A.

1.6 Nondestructive test personnel certification. Personnel performing nondestructive testing shall be certified in accordance with the guidelines of ASNT SNT-TC-1A. Each activity shall develop a written practice, as required by ASNT SNT-TC-1A, identifying the requirements relative to the guidelines. The written practice shall be made available to the Government inspector upon request. The guidelines of ASNT SNT-TC-1A shall be considered as minimum requirements, except as modified herein. Alternatively, individuals certified as Level I, Level II, or Level III in accordance with MIL-STD-410 shall be considered equivalently certified in accordance with this document. Naval (military) personnel only may be certified to the requirements of NAVSEA S9086-CH-STM-020, Chapter 074 Volume 2, as an alternative to the requirements herein.

1.6.1 Examiner personnel testing requirements. Nondestructive test examiner personnel shall be tested by examinations administered by the employing activity, American Society for Nondestructive Testing (ASNT), or other outside agency. The specific examination shall be prepared and administered by the employing activity or an outside agency. The employing activity shall identify minimum passing grade requirements when the basic and method examinations are administered by ASNT, which issues grades on a pass/fail basis. In this case, the passing grade for the basic and method examination shall be assigned a numerical score of 80 percent.

1.6.1.1 Hours of training and experience. The number of hours of training and experience for all nondestructive test personnel shall be in accordance with ASNT SNT-TC-1A. However, the hours for personnel who perform only one operation of a nondestructive test method that consists of more than one operation, or perform nondestructive test examinations of limited scope, may be less than those specified in ASNT SNT-TC-1A, provided the time of training and experience is described in the written practice, and any limitation or restriction on the certification is described in the written practice and in certification records.

1.6.1.2 Other methods. For nondestructive test methods not covered by ASNT SNT-TC-1A, personnel shall be qualified to comparable levels of competency by the administration of comparable examinations on the particular method involved.

1.6.2 Certification of personnel. The employing activity is responsible for the adequacy of the program and is responsible for the certification of all levels of nondestructive test personnel.

1.6.3 Recertification. Nondestructive test personnel other than examiners shall be recertified by examination at intervals not greater than 3-years in accordance with the activity's written practice. Examiners (see

1.5.5) shall be recertified by examination at intervals not greater than 5-years. This re-examination shall be as comprehensive as that employed in the initial certification. In addition, personnel who perform NDT shall be recertified by examination if they have not performed tests in the method in which they are certified for a period of 9 months; this re-examination need only consist of an approved operational examination administered by the activity's test examiner.

1.6.4. Re-examination. The Government inspector may request an operational or written examination be administered if there is reason to believe that an individual is unable to competently perform at the level that the individual is certified.

1.6.5. Alternate certification. Personnel qualified to specific inspection methods/techniques in accordance with MIL-STD-2132 or NAVSEA 250-1500-1 (Limited Distribution) certification programs are considered qualified for performance of inspection in accordance with the requirements of this document for the same inspection methods/techniques. The use of personnel qualified to specific inspection methods/techniques of other certification programs shall require NAVSEA approval.

1.6.6 Vision tests

1.6.6.1. General. All nondestructive test personnel shall be required to pass a vision test. The vision test must be current at the time of examination and vision tests shall be conducted annually. Vision testing shall be conducted by a qualified technician, using standard test methods for determining visual acuity. The standard of acceptance for vision tests shall be:

(a) Natural or corrected near distance acuity such that the individual is capable of reading J1 letters on the Standard Jaeger's Test chart for near vision, or equivalent type test. This requirement must be met by one or both eyes.

(b) Ability to distinguish between colors when required by the work (need only be performed for initial qualification).

1.6.6.2. Vision correction. The corrective aids used for vision tests must be used during certification examination and all subsequent inspections and tests performed.

1.6.7. Records. Employing activities shall maintain individual nondestructive test personnel records including the following:

(a) Training and experience.
(b) Results of all current examinations which can be correlated to the examination administered and a master copy of each examination. When ASNT is used for examiner certification, the ASNT letter may be used for the basic and method examinations.
(c) A record of vision tests noting corrective aids used.
(d) Records shall be maintained for the current and preceding certification period unless otherwise stated.

All of the above records shall be made available to the Government inspector upon request.

1.6.8. NDT certification transfer. Transfer of NDT certifications to other activities is prohibited except as authorized by NAVSEA.

1.7. Procedure qualification and approval. Nondestructive testing methods shall be performed in accordance with written procedures.

1.7.1. Development and certification. Activities performing NDT shall develop and maintain a written procedure for each method performed and certify that each procedure is in accordance with the requirements of this document This certification statement shall be part of each written procedure and signed by the cognizant examiner of the activity.

1.7.2. Qualification. Each procedure shall have been qualified by proving that known discontinuities, either natural or artificial, can be reliably detected and evaluated. Data documenting this procedure demonstration shall be provided to the Government inspector upon request. This requirement does not apply to procedures approved under revisions "E" and earlier of MIL-STD-271, Requirements for Nondestructive Testing Methods (superseded by this document).

1.7.3. Approval. Procedures shall be approved by the cognizant examiner of the activity and provided to the Government inspector for review upon request. The Government inspector may request demonstration of the procedure during initial review of the procedure or at any time there is reason to believe it is unable to provide adequate results.

1.7.4. Transfer. Procedures shall not be transferred from one activity to another without the specific approval of NAVSEA.

1.8. Inspection records. For each method, inspection records shall include, as a minimum, the record requirements listed in each inspection method section of this document. Each inspection record may either contain all of the required information, or, the record can contain part of the information with the remainder included in the inspection procedure (for those attributes that do not change).

1.8.1. Maintenance of inspection records. Records shall be maintained as specified in the applicable ship specifications, fabrication specifications, and other documents invoking this document.

2 APPLICABLE DOCUMENTS

2.1. Government documents

2.1.1. Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation (see 9.3).

SPECIFICATIONS

FEDERAL

P-D-680	- Dry Cleaning and Degreasing Solvent.

MILITARY

MIL-I-25135	- Inspection Materials, Penetrants.
DOD-F-87935	- Fluid, Magnetic Particle Inspection, Suspension Medium. (Metric)

STANDARDS

MILITARY

MIL-STD-278	Welding and Casting Standard

MIL-STD-410 - Nondestructive Testing Personnel Qualification and Certification
MIL-STD-792 - Identification Marking Requirements for Special Purpose Components.
MIL-STD-2132 - Nondestructive Examination Requirements for Special Applications (Limited distribution).
MIL-STD-6866 - Inspection, Liquid Penetrant.

2.1.2 Other Government documents, drawings and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

PUBLICATIONS

NAVAL SEA SYSTEMS COMMAND (NAVSEA)

S0600-AA-PRO-070 - Underwater Ship Husbandry Manual, Chapter 7, Nondestructive Testing.
S9086-CH-STM-020 - Chapter 074 Volume 2 Nondestructive Testing of Metals - Qualification and Certification Requirements for Naval Personnel.
250-1500-1 - Welding Standard (limited distribution).

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, BLDG. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

2.2 Non-Government publications. The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation (see 9.3).

AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING (ASNT)

SNT-TC-1A - Recommendeded Practice for Nondestructive Testing Personnel Qualification and Certification
Supplement A - Radiographic Testing Method.
Supplement B - Magnetic Particle Testing Method.
Supplement C - Ultrasonic Testing Method.
Supplement D - Liquid Penetrant Testing Method.
Supplement E - Eddy Current Testing Method.

(Application for copies should be addressed to the American Society for Nondestructive Testing, Inc., 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.)

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

E 317 - Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments.
D 3699 - Standard Specification for Kerosine. (DoD adopted)
E 1025 - Standard Practice for Hole-Type Image Quality Indicators Used for Radiography
E 1079 - Standard Practice for Calibration of Transmission Densitometers
E 1316 - Standard Terminology for Nondestructive Examinations.
E 1444 - Standard Practice for Magnetic Particle Examination. (DoD adopted)

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

AMERICAN WELDING SOCIETY (AWS)

A2.4 - Standard Symbols for Welding, Brazing and Nondestructive Examination. (DoD adopted)

(Application for copies should be addressed to the American Welding Society, Inc., 550 NW LeJeune Road, P.O. Box 351040, Miami, FL 33135.)

NATIONAL CONFERENCE OF STANDARDS LABORATORIES (NCSL)
ANSI/NCSL Z540-1 - Calibration Laboratories and Measuring and Test Equipment - General Requirements

(Application for copies should be addresses to the National Conference of Standards Laboratories, 1800 30th St., Suite 305B, Boulder, CO 80301)

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)
AMS 3040 - Magnetic Particles, Nonfluorescent, Dry Method.
AMS 3041 - Magnetic Particles, Nonfluorescent, Wet Method, Oil Vehicle, Ready-to-use.
AMS 3042 - Magnetic Particles, Nonfluorescent, Wet Method, Dry Powder.
AMS 3043 - Magnetic Particles, Nonfluorescent, Wet Method, Oil vehicle, Aerosol Packaged.
AMS 3044 - Magnetic Particles, Fluorescent, Wet Method, Dry Powder.
AMS 3045 - Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle, Ready-to-use.
AMS 3046 - Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle, Aerosol Packaged.
AMS 3161 - Inspection Oil, Odorless Heavy Solvent
AMS 2641 - Vehicle, Magnetic Particle Inspection Petroleum Base.

(Application for copies should be addressed to the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.)

2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. RADIOGRAPHY

3.1 Intended use. The radiographic test method is primarily used for the detection of discontinuities through the volume of welds and castings in most types of material and in a variety of geometric configurations.

3.2 Definitions. The standard terminology for radiographic nondestructive examination as described in ASTM E 1316 shall apply to this section, except as noted below.

3.2.1 Material thickness (T_m). The material thickness is the nominal thickness or actual thickness, if measured, of the strength member, and does not include reinforcements, backing rings or strips. The strength member is defined as the thinner of the sections being joined (see 3.5.4).

3.2.2 Maximum effective radiation source dimension. The maximum source or focal spot dimension projected on the center of the radiographic film. For example, a cylindrical isotope source whose length is greater than its diameter will have a greater effective radiation source dimension when oriented coaxially in the center of a pipe for a panoramic exposure than when the axis of the source is positioned at right angles to the pipe.

3.2.3 Multiple film technique. A procedure in which two or more films of the same or different speed are used in the same film holder, and exposed simultaneously.

3.2.4 Specimen thickness (T_s). The total thickness to be radiographed including, if present, reinforcements, backing rings, or strips (see 3.5.4). This is the thickness upon which the source-to-film distance is based.

3.3 General requirements. The radiographic method of testing is used for determining the presence of discontinuities in all ferrous and nonferrous metals. Radiographic inspection specified herein is intended to apply to all items requiring radiographic inspection in compliance with applicable specifications, drawings, contracts, or purchase orders, and one of the following shall be used:

(a) X-ray machine.
(b) Iridium-192.
(c) Cobalt-60.
(d) Cesium-137.
(e) The use of other radiation sources requires specific NAVSEA approval.

3.3.1 Extent of radiographic inspection. All acquisition documents, drawings, or both shall specify the extent of radiographic inspection, when it is required. This information shall include the number of areas and items to be radiographed, the point in fabrication when radiography shall be performed, the quality level of inspection, and the acceptance standard to be applied. Drawings specifying radiographic coverage requirements shall employ radiographic symbols that are in accordance with AWS A2.4.

3.3.1.1 Radiographic shooting sketch (RSS) for castings. The casting designer shall select and identify, in accordance with AWS A2.4, areas requiring radiography on the engineering drawing. The contractor or activity performing the inspection shall prepare the RSS which shows film placements and radiation directions to assure adequate radiographic coverage as specified by the engineering drawing. The RSS shall be validated by a signature of a certified radiographic inspector. The requirements of 3.4.14 herein provide specific detailed requirements which shall be contained on the RSS.

3.3.1.2 Inspection of heat-treated items. Radiographic inspection may be performed at the following times:

(a) Before or after stress relief.
(b) Before or after heat treatment where the heat treatment does not require quenching of the item in a liquid medium.

3.3.1.3 Inspection of machined items. Castings or forgings may be radiographed in the as-cast, as-forged, or rough machined conditions, provided the requirements of 3.5.4.2 are met.

3.3.1.4 Inspection of weldments. Weldments that require contouring or machining may be radiographed in the as-welded condition provided the surface condition does not interfere with the interpretation of the radiographs and the penetrameter selection is based on the requirements of 3.5.4.

3.3.2 Radiographic procedure. Radiographic inspection procedures shall contain as a minimum, the following elements.

3.3.2.1 Minimum radiographic procedure requirements.

(a) X-ray machine information.
  (1) Model and type.
  (2) Manufacturer.
  (3) Focal spot size.
  (4) Voltage rating.
(b) Isotope source information.
  (1) Type of isotope.
  (2) Source dimensions (maximum).
(c) Film processing methods.
(d) Film type.
(e) Viewing facilities.
(f) Film density requirements including density measuring equipment used.
(g) Method of providing film identification as specified in 3.4.8.
(h) The requirements of this document that apply.

3.3.2.2 Survey of radiographic facilities. The Government inspector will perform radiographic facilities and procedure surveys of activities to ensure that the organization is performing radiographic inspection in accordance with the requirements of this document. The surveys may be conducted at 12-month intervals unless the quality of radiographic performance dictates a need for more frequent surveillance. The Government inspector will maintain a record of the results of each survey. The records will include sufficient information to establish that the activity is performing radiographic inspection in accordance with its procedure and this document.

3.4 Radiography requirements.

3.4.1 Direction of radiation. Unless otherwise specified, the direction of the central beam of radiation shall be as nearly central to the area being examined and perpendicular to the surface of the film as possible.

3.4.2 Screens and filters. All radiographs produced with radioisotopes or a source of 150 kV or greater shall employ a front and back lead screen in contact with the film. Intensifying screens and filters shall be as follows:

(a) Intensifying screens: For radiation energies up to 300kv (inclusive), either lead oxide or lead foil intensifying screens may be used. For energies above 300kv, only lead foil screens may be used. Intimate contact between the screens and the films should be maintained during exposure.

(b) Front filters: When using radiation sources with energies of 0.7 MeV or greater (including Cobalt-60), a lead filter with a thickness of not less than 0.010 inch shall be placed between the specimen and the film. The filter may be located either in the film holder and may be combined with the intensifying screen, or may be located in front of the film holder. However, if the filter is located in front of the film holder, the screens shall be placed in contact with the film, as in (a) above.

(c) Back filters: Lead filters shall be used behind the film holder to prevent scattered radiation from the floor, walls, air, or other surrounding objects from fogging the film. Each holder shall have a lead letter "B" not less than 1/2 inch high and not less than 1/16 inch thick positioned behind the film and within the area of film to be read. When performing panoramic exposures, one lead letter "B" may be placed in each quadrant. The lead letter "B" is not required for radiography of circumferential welds with an inside diameter less than 3/4 inch which are performed by the single wall exposure technique. If the image of the letter "B" shows a light image on a darker background, the radiograph shall be rejected. A darker image of the letter "B" on a lighter background is not cause for rejection provided the darker image does not interfere with the film evaluation.

3.4.3 Film. Radiographs shall be made on fine grain, extra-fine grain, or ultra-fine grain, safety base film. High-speed, medium or coarse grain films shall be used only when authorized by NAVSEA or its authorized representative.

3.4.3.1 Film quality. Radiographs presented for interpretation shall be free from blemishes or film artifacts which might mask or be confused with defects in the material being examined. If doubt exists concerning the true nature of an indication on the film, the radiograph shall be rejected. Typical blemishes are as follows:

(a) Fogging caused by light leaks in the processing room or cassettes, defective safelights, exposure marks caused by improper processing, or old film.

(b) Mechanical processing defects such as streaking, air bells, water marks, or chemical stains.

(c) Blemishes caused by dirt in cassettes, particularly between intensifying screens and the film.

(d) Pressure or lead marks, scratches, gouges, finger marks, crimp marks, or static electricity marks.

(e) Loss of detail caused by poor film-to-screen contact in localized areas.

3.4.3.2 Film density. The density shall be 1.5 to 4.0 for single film viewing and 2.0 to 4.0 for superimposed film viewing in the area being examined for acceptance. For castings and forgings, the density shall be 1.5 to 4.0 in the area being examined for acceptance for both the single and superimposed film viewing. When the thickness of the part varies considerably in the area under examination, two or more films, either of equal or of different speeds may be exposed simultaneously in the same film holder and the resultant radiograph submitted for interpretation either as single or superimposed film, whichever is better suited for the interpretation of any small portion of the area covered by the exposure. For the small portion of the area under immediate examination, the density of either the single or the superimposed film shall be in accordance with the aforementioned requirements.

3.4.3.3 Multiple film techniques. Film techniques with two or more films of the same or different speeds in the same film holder shall be permitted, provided the applicable radiographic quality level for a specific area is demonstrated.

3.4.4 Filmless techniques. The use of filmless techniques shall be limited to in-process inspection and shall not be permitted for final acceptance inspection unless specifically approved by NAVSEA.

3.4.5 Radiation sources. Recommended X-ray machine voltage settings and gamma-ray sources to be used with various specimen thicknesses are shown on figure 1, figure 2, and figure 3. Other voltage settings or sources may be used provided the required quality levels are maintained. Cobalt 60 sources shall not be used on welds with a specimen thickness (T_s) less than 2.5 inches or on any material with a nominal thickness less than 1 inch. Cobalt 60 may be used on casting repair welds where the specimen thickness is greater than or equal to 1 inch.

3.4.6 Source-to-film distance.

3.4.6.1 Calculations. The source-to-film distance shall be such that the geometric unsharpness (U_g) values of figure 4 are not exceeded. Source-to-film distance (SFD) shall be calculated as follows:

$$SFD = t + \frac{Ft}{U_g}$$

Where:

U_g = Geometric unsharpness in inches.

F = Maximum effective radiation source dimension in inches (see 3.2.2).

t = Specimen thickness T_s in inches.

SFD = Distance, in inches, between radiation source and film.

3.4.6.2 Film-specimen contact. When the film cannot be placed in intimate contact with the specimen, and a gap exists between the specimen and the film, the minimum SFD (as calculated per 3.4.6.1) shall be multiplied by the ratio of:

$$\frac{t + gap}{t}$$

3.4.6.3 Reduced source-to-film distance. When accessibility does not permit compliance with the above, a shorter source-to-film distance is allowed provided the following conditions are met:

(a) The required quality level is obtained.
(b) The greatest possible source-to-film distance is used.
(c) The radiographic record shows what accessibility conditions limited the source-to-film distance and indicates the actual source-to-film distance used.

3.4.7 Radiographic location markers. The images of the location markers for the coordination of the part with the film shall appear on the film without interfering with the interpretation and with such an arrangement that it is evident that complete coverage was obtained. These marker positions shall be marked on the part and the position of the markers shall be maintained on the part during radiography. When using a technique in which radiation passes through two walls and the welds in both walls are viewed for acceptance, and the entire image of the object being radiographed is shown on the radiograph, only one location marker is required on the base metal at the center of the area being examined. Markings shall be in accordance with MIL-STD-792.

3.4.8 Film identification. A system of positive identification of the film shall be used and each film shall have a unique identification relating it to the item being inspected. As a minimum, the following additional information shall appear on each radiograph or in the records accompanying each radiograph:

(a) Identification of the organization making the radiograph.
(b) Date of exposure.
(c) Identification of the part, component, or system and, where applicable, the weld joint in the part, component, or system.
(d) Whether the radiograph is of the original area or a repair area.

3.4.9 Maintenance of radiographic records. Radiographic records shall be maintained as specified in 1.9.1.

3.4.10 Darkroom facilities. Darkroom facilities, including equipment and materials, shall be capable of producing uniform, blemish-free radiographic negatives.

3.4.11 Film viewing facilities. Viewing facilities shall be so constructed as to afford the exclusion of objectionable background lighting of an intensity that may cause reflection on the radiographic film.

3.4.11.1 Film viewing equipment. Equipment used for radiographic interpretation shall provide the following minimum features:

(a) A light source of sufficient intensity controlled to allow the selection of optimum intensities for viewing film densities specified in 3.4.3.2. The required intensity range may be provided by the use of a separate high intensity viewing port. The light enclosure shall be so designed to provide a uniform level of illumination over the entire viewing surface.

(b) A suitable fan, blower, or other cooling device to provide stable temperature at the viewing port such that film emulsions shall not be damaged during 1 minute of continuous contact with the viewing surface.

(c) An opal glass front in each viewing port, except for high intensity viewers used for high density film.

(d) A set of opaque masks to suit the sizes of radiographs to be viewed, or equivalent.

(e) A densitometer meeting the requirements of ASTM E 1079 shall be provided for assuring conformance with film density requirements. The densitometer aperture size shall be not greater than 2 millimeters in diameter.

3.4.12 Surface preparation of components and welds prior to radiography. Metal components shall be free of scale, surface slag, adhering or imbedded sand, or other surface conditions which may interfere with proper interpretation of radiographs. With the exception of undercuts at the toe of the weld which are within specification allowances, the contour of welds shall blend smoothly and gradually into the base metal. Excessive weld ripples or weld surface irregularities shall be removed by any suitable mechanical process to such a degree that the resulting radiographic contrast due to any irregularity cannot mask or be confused with the image of a defect.

3.4.13 Safety. Radiographic tests shall be performed under protected conditions such that personnel shall not receive a whole-body radiation dosage exceeding the maximum permitted by city, state, or national codes.

3.4.14 Interpretation of radiographs. To aid in the proper interpretation of radiographs, a sketch, drawing, written procedure, or equivalent record shall be prepared to show the setup used to make each radiograph. The information shall accompany each radiograph (or a group of radiographs if the same information applies). Reference to a standard setup is acceptable if descriptions of this standard setup are made available. The information shall include:

(a) Number of films and film type.
(b) Location of each film on the radiographed item.
(c) Orientation of location markers.
(d) Location of radiation source, including source-to-film distance and approximate angle of beam.
(e) The kilovoltage and focal spot size (for X-ray machines).
(f) The isotope type, intensity (in curies), and physical dimensions.
(g) Type of material, and material thickness.
(h) Shim or block material, and thickness.
(i) Type of weld joint, for example, butt with backing ring.
(j) Whether original or repair.
(k) Part and drawing number.
(l) Material groups, penetrameter sizes and types (MIL-type or ASTM-type) and the required quality level.
(m) Source-side or film-side penetrameter.
(n) Single- or double-wall viewing.
(o) Type and thickness of intensifying screens and filters.
(p) Applicable acceptance standards.
(q) Signature of the radiographic operator.
(r) Approved procedure identification.

3.4.15 Radiographic records. Radiographic records shall contain the following:

(a) The information specified in 3.4.14.
(b) Notation of acceptable and rejectable discontinuities. Any questionable discontinuity in the area of interest which is due to a surface condition shall be visually verified and noted.
(c) Date of interpretation.
(d) Disposition (accept/reject) of the item radiographed.
(e) Signature of the radiographic inspector.

3.4.16 Availability of radiographs. Radiographs and records shall be made available to the Government inspector upon request.

3.5 Penetrameters. Penetrameters shall be employed for all radiographs, except as specified in 3.5.5.4, and the penetrameter image will be employed to determine the radiographic quality level. Either MIL-type penetrameters (as defined in the following paragraphs), or ASTM-type penetrameters (as defined in ASTM E 1025) may be used. None of the requirements of this document which apply to physical size, marking, etc. of penetrameters shall be interpreted as applying to ASTM-type penetrameters. The film density of the penetrameter image shall be not greater than 15 percent more than the film density of the area of interest. It may be less dense than the film density of the area of interest. The film density of the penetrameter shall be measured directly over the penetrameter hole used to obtain the required sensitivity.

3.5.1 Penetrameter material. Material grouping for penetrameter material shall be as follows, except that penetrameters of a lower group number (Group 03 is lowest) may be used for any material group of a higher number providing the applicable quality level is maintained. For material not listed, the penetrameter material shall be as specified in 3.5.1.2.

Material, Group 03	Penetrameters, Group 03
Magnesium	Magnesium

Material, Group 02	Penetrameters, Group 02
Aluminum	Aluminum

Material, Group 01	Penetrameters, Group 01
Titanium	Titanium

Material, Group 1	Penetrameters, Group 1
Carbon steel Alloy steel Stainless steel Manganese-nickel-aluminum bronze	Penetrameters made of any of these materials may be used interchangeably.

Material, Group 2	Penetrameters, Group 2
Aluminum bronze Nickel-aluminum-bronze	Penetrameters made of any of these materials may be used interchangeably.

Material, Group 3	Penetrameters, Group 3
Nickel-chromium-iron alloy	Nickel-chromium-iron alloy.

Material, Group 4	Penetrameters, Group 4
Nickel-copper alloys Copper-nickel alloys	Penetrameters made of any of these materials may be used interchangeably.

Material, Group 5	Penetrameters, Group 5
Tin bronze Gun metals Valve bronze	Penetrameters made of any of these materials may be used interchangeably.

3.5.1.1 Dissimilar metal welds.

3.5.1.1.1 Dissimilar metal welds of same group. For welds made between dissimilar metals in any one group, the penetrameters for that group or penetrameters of a lower group number shall be used, provided the quality level as applicable is maintained.

3.5.1.1.2 Dissimilar metal welds of different groups. For welds made between dissimilar metals not of the same materials group, two penetrameters shall be used, one on each side of the weld, of the material group (or lower group) corresponding to the base material upon which it is placed. The use of a single penetrameter is allowed, provided that the lower group number penetrameter is placed on the higher group number material, and the applicable quality level is obtained.

3.5.1.2 Other metals. For radiography of materials not herein covered, penetrameters of the same material may be used, or penetrameters of any other material may be used if the following requirements are met. Two blocks of equal thickness, one of the material to be radiographed and one of the material of which the penetrameters are made, shall be radiographed on the same film by one exposure at the lowest energy level to be used for the production radiographs. Densitometer readings for both materials shall be read from the film and shall be between 2.0 and 4.0 density for both materials. If the film density for the material to be radiographed is within plus 15 percent or less than the film density for the penetrameter material, the penetrameter material may be used for radiography of the production material.

3.5.2 Penetrameter dimensions. The dimensions of MIL-type penetrameters shall conform to those shown on figure 5.

3.5.3 Penetrameter identification. MIL-type penetrameters shall be identified with lead numbers or engraved lead strips indicating the material thickness (T_m or T_s as applicable) to which the penetrameter applies as specified in table I. Examples of corresponding identification numbers for ASTM-type penetrameters are also shown for reference.

(a) MIL-type rectangular penetrameters shall be identified with lead numbers attached to the penetrameters, as shown on figure 5.
(b) For MIL-type penetrameters, the lead numbers shall indicate the material thickness in hundredths of an inch up to 1 inch, and in inches to the nearest tenth of an inch over 1 inch.
(c) Each MIL-type penetrameter shall be further identified by permanently marking its metal or principal alloy composition into the surface of the penetrameter, and by notches in accordance with figure 6.

TABLE I. Examples of penetrameter identification.

MIL-type penetrameter identification number 2/	Penetrameter thickness (inches)	Material thickness 1/ (inches)	ASTM-type penetrameter identification number 2/
25	0.005	0.25	5
50	0.010	0.50	10
75	0.015	0.75	15
1.0	0.020	1.0	20
1.5	0.030	1.5	30
2.0	0.040	2.0	40
3.0	0.060	3.0	60
5.5	0.110	5.5	110
9.0	0.180	9.0	180
10.0	0.200	10.0	200

1/ The 0.005-inch thick penetrameter shall be used for material thickness less than 0.25 inch unless otherwise specified in the applicable specification or purchase order.

2/ For 2 percent sensitivity.

3.5.3.1 Lead number placement for circular penetrameters. Lead numbers shall be placed adjacent to the circular penetrameters to provide identification of the penetrameter on the film.

3.5.3.2 Identification for special quality levels. For the special quality levels of 1-1T and 1-2T, the applicable penetrameter size shall be based on one-half of the material thickness. For the special quality level of 4-2T, the applicable penetrameter size shall be based on twice the material thickness.

3.5.4 Penetrameter selection.

3.5.4.1 Welds. Penetrameter selection shall be based on material thickness T_m as defined in 3.2.1 for piping, machinery, and pressure vessel welds, and on T_s as defined in 3.2.4 for structural welds. For double-wall viewing (see 3.8.2.2), the penetrameter shall be based on $2T_m$ or $2T_s$ as appropriate.

3.5.4.2 Castings and forgings. Castings or forgings may be radiographed in the as-cast, as-forged, or rough machined conditions provided the surface condition does not mask rejectable defects and the following requirements for penetrameter selection are met:

(a) Structural castings and forgings: The penetrameter shall be based on the actual or nominal thickness of the material being radiographed (T_s as defined in 3.2.4). For single-wall viewing, the penetrameter shall be based on T_s. For double-wall viewing, the penetrameter shall be based on $2T_s$.

(b) Other castings and forgings: The penetrameter thickness shall be based on the actual or nominal thickness of the material being radiographed (T_s as defined in 3.2.4). For single-wall viewing, the penetrameter shall be based on T_s. For double-wall viewing, the penetrameter shall be based on $2T_s$. However, if the thickness to be radiographed exceeds the nominal thickness of the finished piece, the penetrameter size shall be based on a thickness which is not greater than the nominal thickness of the finished piece by more than 20 percent or 1/4 inch, whichever is greater. The penetrameter size shall not be based on a thickness greater than the actual thickness to be radiographed. For areas in castings which have been end-prepared for welding, the penetrameter shall be selected based on the actual or nominal thickness of the area adjacent to, but exclusive of, the weld end-preparation.

(c) Any exceptions to the foregoing shall be designated on the drawings or shooting sketches and shall require specific approval of NAVSEA or its authorized representative.

3.5.5 Number, location, and placement of penetrameters.

3.5.5.1 Penetrameter location. The penetrameter shall be placed on the source side of the section being examined (see figure 7, figure 8, figure 9, figure 10 and figure 11). In the inspection of irregular objects, the penetrameter shall be placed on the part of the object farthest from the film. When performing double-wall radiography, the penetrameter shall be placed on the surface of the wall or walls being evaluated nearest the source of radiation (see figure 12). Where this is not practicable, the film side technique specified in 3.5.5.1.1, 3.5.5.1.2, the separate block technique of 3.5.5.1.3, or the technique shot approach of 3.5.5.4, as appropriate, may be employed.

3.5.5.1.1 Film-side penetrameter technique (double-wall exposure). The film-side penetrameter placement technique shall be as shown on figure 13. The radiographic technique shall be demonstrated in a similar section with the applicable penetrameter placed on the source side of the wall for which radiography is desired, and a series of penetrameters, ranging in thickness from that of the penetrameter required on the source side to one-fourth that thickness, shall be placed on the film side. If the proper penetrameter on the source side indicates the required quality level, the image of the smallest hole in the thinnest penetrameter clearly visible on the film side shall be used to determine the penetrameter and the penetrameter hole to be applied in evaluating production radiographs. Technique radiographs shall be made available for review upon request by the Government inspector. Table II contains a list of film side penetrameters which may be used in lieu of performing technique radiography and selection of penetrameters as described above.

3.5.5.1.2 Film-side penetrameter technique (single-wall exposure). For large diameter pipe (8-inch and over) where the diameters are such that the source may be placed inside the pipe for simultaneous single-wall radiography of welds but source-side penetrameter placement is not feasible, a film-side penetrameter technique may be employed provided the requirements of 3.4.6 and the radiographic quality level of the source-side penetrameter being 2-2T as required by 3.7 are met. When using an Iridium-192 source, the required source-side penetrameter may be selected from table III for the applicable wall thickness for single-wall viewing technique, or 2-4T for welds less than 3/4 inch thick, whichever is less restrictive, and the film-side penetrameter selected from table II.

TABLE II. Allowable film-side penetrameters. 1/

Required source-side penetrameter		Allowed film-side penetrameter		Required source-side penetrameter		Allowed film-side penetrameter	
Size	Sensitivity	Size	Sensitivity	Size	Sensitivity	Size	Sensitivity
25	2T	25	2T	70	4T	65	4T
30	2T	25	4T	75	2T	70	2T
35	2T	30	4T	80	2T	75	2T
40	2T	35	4T	85	2T	80	2T
45	2T	40	4T	90	2T	85	2T
50	2T	45	2T	95	2T	90	2T
50	4T	45	4T	1.0	2T	95	2T
55	2T	50	2T	1.2	2T	1.0	2T
55	4T	50	4T	1.5	2T	1.0	2T
60	2T	55	2T	1.7	2T	1.0	2T
60	4T	55	4T	2.0	2T	1.0	2T
65	2T	60	2T	2.2	2T	1.2	2T
65	4T	60	4T	2.5	2T	1.2	2T
70	2T	65	2T	2.7	2T	1.5	2T

1/ Only MIL-type penetrameter sizes are shown. If ASTM-type penetrameters are used, substitute the corresponding ASTM penetrameter size.

TABLE III. Minimum radiographic quality levels for Iridium-192 radiography of castings and welds in piping, machinery and pressure vessels.

Actual or nominal wall thickness (inches)	Type of exposure and viewing technique	Source-side penetrameter number 1/	Nominal penetrameter thickness (inches)	Minimum perceptible hole	Nominal diameter of penetrameter hole (inches)
Up to 0.199	Double-wall exposure Double-wall viewing	50	0.010	4T	0.040
0.200 - 0.235		55	.011	4T	.044
.236 - .275		60	.012	4T	.048
.276 - .298		65	.013	2T	.026
.299 - .321		70	.014	2T	.028
.322 - .343		75	.015	2T	.030
.344 - .359		80	.016	2T	.032
.360 - .375		85	.017	2T	.034
.376 - .432		90	.018	2T	.036
.433 - .489		95	.019	2T	.038
.490 - .547		1.0	.020	2T	.040
Up to 0.500	Single-wall viewing (Single- or double-wall exposure)	50	0.010	4T	0.040
0.501 - .555		55	.011	4T	.044
.556 - .600		60	.012	4T	.048
.601 - .642		65	.013	2T	.026
.643 - .684		70	.014	2T	.028
.685 - .725		75	.015	2T	.030
.726 - .816		80	.016	2T	.032
.817 - .906		85	.017	2T	.034

1/ This penetrameter is to be used for both insert and backing ring joints regardless of the amount of reinforcement or thickness of backing ring. Only MIL-type penetrameter sizes are shown. If ASTM-type penetrameters are used, substitute the corresponding ASTM penetrameter size.

3.5.5.1.3 Separate block penetrameter technique. The penetrameter may be positioned on a block of the same or a lower group number material placed as close as possible to the area being radiographed. The block shall be of thickness equal to or greater than the thickness of the item being radiographed and, in piping 1-inch nominal pipe size and larger, shall be positioned so that the penetrameter is at the same distance from the film as it would be if placed on the source side of the item being radiographed.

3.5.5.2 Requirements for casting and forgings. One penetrameter shall represent an area within which radiographic densities do not vary more than plus 30 percent to minus 15 percent from the density measured as specified in paragraph 3.5. Not less than one penetrameter per radiograph shall be used except as specified in 3.5.5.4. If a shim is used, it shall be of the same or lower group number as the item being radiographed. When the film density varies by more than minus 15 to plus 30 percent, two penetrameters used as follows will be satisfactory. If one penetrameter shows an acceptable sensitivity at the most dense portion of the radiograph, and the second penetrameter shows an acceptable sensitivity at the least dense portion of the radiograph, these two penetrameters shall serve to qualify the radiograph within the density limits. For components where there are changes in wall thickness and wall alignment, and the use of two penetrameters is not practical, the use of one penetrameter is approved. The required penetrameter density tolerance need not be met; however, the density in areas of interest shall be between 1.5 and 4.0. Where only one penetrameter is used, the penetrameter size shall be based on the thinnest wall being radiographed and shall be placed on the thickest wall section.

3.5.5.3 Requirements for welds. The number and placement of penetrameters for specific configurations shall be as specified in table IV and the following.

3.5.5.3.1 Penetrameter image position. The image of the penetrameter or the shim on which the penetrameter is placed shall not be superimposed on the weld in the area being evaluated.

3.5.5.3.2 Penetrameter image location. Where possible, the image of the penetrameter shall be not greater than 1-1/4 inches from the edge of the weld as shown on the radiograph.

3.5.5.3.3 Penetrameters on weld. Penetrameters may be placed on the weld outside the area to be read for acceptance.

3.5.5.3.4 Penetrameter orientation. Penetrameters may be placed with the long axis either parallel or perpendicular to the length of the weld.

3.5.5.3.5 Obstructions. When part geometry or access will not permit placement of the penetrameter at one or both extremities, the penetrameter shall be placed within 1 inch of the obstruction. A lead source-side marker shall be placed on the adjacent base material at the extremity of the area to be viewed for acceptance. If access to adjacent base material is restricted, the marker shall be placed on the weld. If the extremity of the area of interest is obvious on the radiograph (that is, the end of a plate, a weld intersection, and so forth), the additional marker is not required.

3.5.5.3.6 Tapered and fillet welds. Tapered and fillet-type welds shall have a minimum of two penetrameters representing the minimum and maximum weld thickness (see figures 14 and 15). However, one penetrameter may be used for small differences in thickness, provided the penetrameter size is based on the thinner section and it is placed on the thicker weld section and the film density of the penetrameter image is not greater than 15 percent more than the lightest film density in the area of interest.

3.5.5.4 Radiography of parts. Penetrameters are not required on each film when placement of the penetrameter on the part would obscure part or all of the area of interest, and where it would not be practicable to place the penetrameter on a block adjacent to the part, as specified in 3.5.5.1.3. However, an initial technique shot with the applicable penetrameter on the part shall demonstrate the specified penetrameter hole, and subsequent exposure without a penetrameter shall be made only if exposed in the same

TABLE IV. Number of penetrameters and placement for welds.

Weld Configuration	Inspected weld length (inches)	Penetrameters	
		Minimum number	Placement 1/
Welds in curved surfaces less than 24 inches in diameter.	5 and less	1	At the center of the area of interest.
	Greater than 5	2	One at the extremity and one at the center of the area of interest, or one at each extremity of the area of interest.
Welds in flat surfaces and curved surfaces 24 inches and greater in diameter (includes longitudinal welds in pipes and pressure vessels).	Less than 10	1	At the center of the area of interest.
	10 up to and including 17	2	One placed at each extremity of the area of interest.
	Greater than 17	3	One placed at each extremity and one at the center of the area of interest.
Essential circular (non cylindrical welds on one film)	Unlimited	2	Approximately 180 degrees apart at the extremity of the area being inspected.
Cylindrical welds radiographed simultaneously using a series of films or a single length of roll film (panoramic exposure).	Unlimited	4	One in each quadrant
Repairs in cylindrical welds initially radiographed using panoramic exposure technique.	Unlimited	1	One in each affected quadrant, provided the technique used is the same as the initial radiograph.

1/ Penetrameter placements specified for longer inspected weld lengths may be used for shorter weld lengths within each weld configuration.

manner as the technique shot. Whenever the setup is changed, and at intervals not greater than once each work shift, additional technique shots shall be made in proper sequence to assure that the process is being properly controlled. The technique shots shall accompany the subsequently exposed film when presented for interpretation by the radiographic inspector of each organization or for review by the Government inspector. If multiple parts or components are exposed simultaneously, at least one penetrameter shall be required on each film plus additional penetrameters as required by table IV.

3.6 Shims. When a weld reinforcement or backing ring or backing strip are not removed, a shim of material which is of the same or a lower group number as the backing ring or strip shall be placed under the penetrameter to provide the same or a greater thickness of material under the penetrameter as the average thickness of the weld reinforcement plus the wall thickness and the backing ring. The shim shall exceed the penetrameter dimensions on all sides, and shall be placed so as not to overlap the reinforcement.

3.6.1 Shims for backing ring welds. When weld images are superimposed, the thickness of the shims shall be equal to or greater than twice the average thickness of the weld reinforcement plus twice the thickness of the backing ring.

3.6.2 Shims for consumable insert welds. When weld images are superimposed, the thickness of the shims shall be equal to or greater than twice the average thickness of the outside reinforcement plus twice the average thickness of the inside reinforcement.

3.7 Radiographic quality levels. Unless otherwise specified in the applicable specification, contract, or drawing, the radiographic quality level shall be 2-2T, except as noted in 3.7.1 and 3.7.2. Penetrameter identification, definition of radiographic quality level, and design are specified in table I, table V, and figures 5 and 6, respectively.

(a) Standard radiographic quality levels.

(1) 2-2T: This requires that a penetrameter whose thickness (T) is no greater than 2 percent (1/50) of the material thickness of the item being radiographed and a hole drilled through the penetrameter with a diameter equal to twice the thickness of the penetrameter (2T) shall be visible.

(b) Special radiographic quality levels.

(1) Quality level 1-1T radiography: The 1T hole in a penetrameter whose thickness (T) is no greater than 1 percent (1/100) of the material thickness shall be visible.

(2) Quality level 2-1T radiography: The 1T hole in a penetrameter whose thickness (T) is no greater than 2 percent (1/50) of the material thickness shall be visible.

(3) Quality level 1-2T radiography: The 2T hole in a penetrameter whose thickness (T) is no greater than 1 percent (1/100) of the material thickness shall be visible.

(4) Quality level 2-4T radiography: The 4T hole in a penetrameter whose thickness (T) is no greater than 2 percent (1/50) of the material thickness shall be visible.

(5) Quality level 4-2T radiography: The 2T hole in a penetrameter whose thickness (T) is no greater than 4 percent (1/25) of the material thickness shall be visible.

3.7.1 X-ray radiography. For welds under the following conditions, a 2-4T quality level is acceptable:

(a) For butt welds with permanent backing, where the material thickness (T_m) is less than 1/2 inch.

(b) For penetration and connection welds (figure 14 and figure 15) where the T_{m1} thickness is less than 2 inches.

3.7.2 Radioisotope radiography. When radioisotopes are used, the quality level and selection of penetrameter shall, as a minimum, be in accordance with table III. For welds and components not specified in table III, the 2-4T quality level is acceptable under the following conditions:

(a) Penetration and connection welds (figures 14 and 15) when the T_m thickness is not greater than 2 inches (applicable to all isotopes).

(b) Components and welds, other than above, when the T_m is not greater than 3/4 inch (applicable to Iridium-192 only).

TABLE V. Definition of radiographic quality levels.

Radiographic quality level	Max penetrameter thickness1/ (percent)	Min perceptible hole diameter2/	Equivalent penetrameter sensitivity3/ (percent)
1-1T	1	1T	0.7
1-2T	1	2T	1.0
2-1T	2	1T	1.4
2-2T	2	2T	2.0
2-4T	2	4T	2.8
4-2T	4	2T	4.0

1/ Expressed as a percentage of the material thickness.
2/ Expressed as a multiple of thickness of penetrameter (T).
3/ Equivalent penetrameter sensitivity is that thickness of the penetrameter, expressed as a percentage of the material thickness, in which a 2T hole would be visible under the same radiographic conditions.

3.8 Single-wall and double-wall radiography.

3.8.1 Single-wall radiography. Radiographs shall be made through single wall whenever practical. Shims under the penetrameter shall be as specified in 3.6. For cylindrical welds in piping, double-wall radiography is permitted as specified below.

3.8.2 Double-wall radiography.

3.8.2.1 Double-wall exposure/single-wall viewing. For welds in pipe greater than 3-1/2 inches nominal pipe size, only the weld closest to the film shall be viewed for acceptance. The source shall be positioned in such a location that the source-side weld image does not obscure the image of the film-side weld. Shims under the penetrameter shall be provided in accordance with 3.6. The minimum source-to-film distance shall be calculated based on the T_s value illustrated on figure 13 and 3.4.6.

3.8.2.2 Double-wall exposure/double-wall viewing. Welds in pipe or tube 3-1/2 inches or less nominal pipe size may be radiographed using a technique in which the radiation passes through two walls and the weld in both walls is viewed for acceptance on the same film. The radiation beam may be offset from the plane of the weld at an angle sufficient to separate the images of source-side and film-side portions of the weld. Shims under the penetrameter shall be provided in accordance with 3.6. The minimum source-to-film distance shall be calculated using the outside diameter of the pipe or section as the specimen thickness T_s (see figure 12 and 3.4.6).

3.9 Radiography of repair welds. When weld repairs are made to castings and forgings, to remove defects revealed by radiography, the original radiographs of the previously defective areas shall be submitted for review with the final acceptance radiographs. For those items where radiography is required for the repair, a sketch showing the location, size, and shape of the repair weld shall accompany the radiograph. Penetrameters, location markers, or film identification shall not be placed in the weld repair areas being inspected.

3.10 Radiography of castings and forgings. Whenever possible a single-wall technique shall be used; however, for casting and forging areas with nominal internal dimensions 4 inches or less a double-wall technique may be used. The minimum source-to-film distance shall be calculated using the outside diameter of the item radiographed as specimen thickness T_s.

3.11 Radiographic film ownership. Unless otherwise specified, radiographic film and the associated inspection records of an item shall become the property of the purchaser of the item. Maintenance of radiographic records shall be as specified in 1.9.1.

4. MAGNETIC PARTICLE TESTING

4.1 Intended use. The inspection process is intended for the detection of surface or near surface discontinuities in ferromagnetic materials. Drawings specifying magnetic particle inspection shall employ symbols in accordance with AWS A2.4.

4.2 Definitions. The standard terminology for magnetic particle examination as described in ASTM E 1316 shall apply to this section, except as noted below.

4.2.1 Relevant indications. Accumulations of magnetic particles caused by discontinuities in the item tested which shall be evaluated to the applicable acceptance criteria.

4.2.2 Indication. Any magnetically held magnetic particle pattern on the surface of a part being tested.

4.2.3 Non-relevant indications. Accumulations of magnetic particles held to a particular area caused by conditions which have no bearing on the suitability of the part for service. Examples of such indications are as follows:

(a) Magnetic writing: Indication is fuzzy and will be destroyed by demagnetization. These indications are caused by contact with other steel or magnets while magnetized.

(b) Change in section: Indications are broad and fuzzy caused by concentration of magnetic field.

(c) Flow lines: These are large groups of parallel indications which occur in forgings under excessive currents.

(d) Change in permeability: These are areas in the material where the magnetic "strength" changes.

4.3 Magnetic particle inspection requirements.

4.3.1 General requirements.

4.3.1.1 Method. Magnetic particle inspection may be performed by either the wet or dry method. Unless otherwise specified, the inspection zone for welds shall include the weld and 1/2 inch of adjacent base material, where possible.

4.3.1.1.1 Lighting in test area. The test area shall be adequately illuminated for proper evaluation of indications revealed on the test surface. When fluorescent magnetic particle material is used, the inspection shall be accomplished in a darkened area using black light (ultraviolet light). The black light shall be capable of producing an intensity of 800 micro-watts per square centimeter on the inspection surface. Intensity shall be measured daily, and after bulb replacement. Not less than 5 minutes shall be allowed for the lamp to obtain full brilliance before beginning the inspection.

4.3.1.2 Procedure. All magnetic particle procedures shall include as a minimum the following information:

(a) Material, shapes, and sizes to be tested.
(b) Type and direction of magnetization to be used.
(c) Equipment to be used for magnetization.
(d) Surface preparation (finishing and cleaning).
(e) Whether wet or dry method is to be used.
(f) Type of magnetic particles to be used.
(g) Whether continuous or residual method is used.

(h) Magnetizing current (amperage, alternating current (ac) or dc).
(i) Demagnetization.
(j) Test for concentration of particle suspension (if any).
(k) Sketches or a chart showing the typical inspection grid to be used.
(l) Method of particle application and removal.
(m) Applicable acceptance standards.
(n) Method for determining maximum coating thickness (if any).

For the inspection of welds, the magnetic particle inspection procedure shall have the proven ability to detect a 1/16 inch long by 0.006 inch wide by 0.020 inch deep notch (maximum dimensions) oriented 90 degrees to the magnetic flux. The notch shall be cut in a 3/8-inch low alloy steel plate and shall be filled flush with a nonconducting material, such as epoxy, to prevent mechanical holding of the indication medium.

4.3.1.3 Inspection through coatings. Magnetic particle inspection shall not be performed with coatings in place that could prevent the detection of surface defects in the underlying material. In addition, the procedure must be qualified with a coating of the same type and maximum possible thickness which will be encountered in the actual inspection. Furthermore, the procedure must also contain specific instructions as to what method the inspector is to employ to determine the maximum coating thickness in the area to be inspected. For non-ferromagnetic coating thicknesses of 0.003 inches and less, the qualification sample need not be coated.

4.3.1.4 Surface preparation. Prior to inspection, surfaces shall be dry and free from any contamination which might interfere with the proper formation or interpretation of the magnetic particle patterns. With the exception of undercuts which are within specification allowances, the contour of welds shall blend smoothly and gradually into the base metal. Surface irregularities shall be removed to the extent that they will not interfere with interpretation of the test results. The final magnetic particle inspection shall be performed in the final surface and heat-treated conditions as specified in 1.4.

4.3.1.4.1 Cleaning and masking. Grease or other matter which might interfere with the proper distribution and concentration, or with the intensity, character, or definition of magnetic particle indications shall be removed from the surface undergoing the tests. All openings shall be plugged to prevent accumulation of magnetic particles or other matter where it cannot be completely or readily removed by washing and air blasting.

4.3.1.4.2 Cleaning solution. Chlorinated solvents shall not be used on parts containing crevices.

4.3.1.5 Direction of magnetization. To ensure detection of discontinuities having axes in any direction, not less than two separate inspections shall be carried out on each area. The second inspection shall be with the magnetic field at right angles to that used in the first inspection. A different means of magnetizing may be employed for the second inspection of the area.

4.3.1.6 Demagnetizing apparatus. Demagnetizing equipment shall consist of units, such as the open coil or box-type demagnetizer, with sufficient capacity to demagnetize the item.

4.3.1.6.1 Demagnetization. All items shall be demagnetized at the following stages to obtain satisfactory indications of discontinuities:

(a) Prior to testing, if the material contains strong remnant fields from some previous operation or inspection.
(b) After all magnetic particle testing is completed, if the remnant field interferes with the removal of the magnetic particles in cleaning the part or when specified in the appropriate equipment specification.

4.3.1.7 Equipment accuracy. Magnetic particle testing equipment shall be checked for accuracy at the time of purchase and at an interval not greater than 6 months and whenever electrical maintenance is performed which may affect the equipment accuracy. Yokes are exempt form the 6 month retest schedule.

4.3.1.7.1 DC portable prod and stationary magnetic particle equipment. To check the equipment ammeter, a suitable calibrated ammeter shall be connected in series with suitable shunts and the current through the electrodes measured. The amperage measured by the calibrated ammeter during the test shall simultaneously be compared to that indicated on the meter of the magnetic particle equipment. The equipment meter shall agree (within 5 percent of full scale) with the current measured by the calibration meter.

4.3.1.7.2 Yoke equipment. Yokes shall be checked for adequacy of magnetization strength. With the pole spacing set to the maximum that the yoke will be used for, the lifting power, as applied to carbon or alloy steel, shall be not less than 10 pounds for ac electromagnetic yokes and 40 pounds for dc or permanent magnet yokes.

4.3.1.8 Magnetizing current. The magnetizing current shall be based on formulas provided herein or the current shall be determined by means of a segmented magnetic particle field indicator as shown on figure 16. Where examination is being performed on complex shapes, the field indicator shall be used to determine the adequacy of the field. The current or technique shall be modified as necessary to ensure that an adequate field is present on all surfaces to be examined.

4.3.1.9 Record requirements. Records of magnetic particle inspections shall contain the following:

(a) Description and unique identification of item inspected.
(b) Approved procedure identification.
(c) Instrument manufacturer and model number, or unique equipment identification (yokes excluded).
(d) Acceptance standard used.
(e) Date of inspection.
(f) Signature(s) of inspector(s).
(g) Disposition (accept/reject) of the item inspected.

4.3.2 Wet method.

4.3.2.1 General requirements. Finely divided magnetic particles shall be suspended in a liquid vehicle as the indicating material. The magnetic particles may be either fluorescent or nonfluorescent. All particles shall meet the requirements of AMS 3041, 3042, 3043, 3044, 3045, or 3046 as applicable.

4.3.2.1.1 Equipment. The magnetizing apparatus shall be capable of inducing, in the item under test, a magnetic flux of suitable intensity in the desired direction by either the circular or the longitudinal method.

4.3.2.2 Vehicles. The liquid used as a vehicle for both nonfluorescent and fluorescent magnetic particles shall comply with the following:

(a) Petroleum distillate conforming to the following specifications shall be used:
    (1) P-D-680
    (2) ASTM D 3699
    (3) SAE AMS 3161
    (4) SAE AMS 2641
    (5) DOD-F-87935
(b) Tap water with suitable rust inhibitors and wetting and antifoaming agents may be substituted for the petroleum distillate.
(c) Liquid vehicles used with fluorescent magnetic particles shall be nonfluorescent.

4.3.2.2.1 Cleaning and drying. Prior to the application of the suspension, all oil, grease, or other foreign matter shall be thoroughly removed from the surface to be tested. Following the removal of the suspension, the piece shall be thoroughly cleaned and dried.

4.3.2.3 Magnetic particles. Magnetic particles shall be nontoxic and shall exhibit good visual contrast. Fluorescent magnetic particles shall be readily visible when exposed to a filtered black light, as specified in 4.3.1.1.1.

4.3.2.4 Suspensions. Suspensions shall consist of the liquid vehicle and either fluorescent or nonfluorescent magnetic particles, but both types of particles shall not be used simultaneously. Concentration of the suspensions shall be maintained as specified in 4.3.2.6.1.

4.3.2.5 Procedure. Suspensions shall be applied to items being tested by spraying or immersion to ensure thorough coverage of areas requiring tests.

4.3.2.5.1 Continuous method. For the continuous method, the magnetizing circuit shall be energized just before diverting the stream of suspension from the item being tested, or just before removing the item from the suspension if testing is by immersion, and allowed to remain energized for not less than 1/5 second, with the result that the magnetizing current is applied while the item is still covered with a film of suspension sufficient to give satisfactory indications.

4.3.2.5.2 Residual method. For the residual method, the item shall be magnetized by the application of direct current (DC) for not less than 1/5 second, after which the magnetizing current shall be turned off and the suspension shall be applied either by spraying or by immersion in the suspension. For application by immersion, the item shall be removed carefully from the suspension to avoid washing off the indications. The residual method shall be used only for inspection of small parts, such as nuts, bolts, pins, gears, and others.

4.3.2.5.3 Circular magnetization; central conductor (indirect method). A central conductor shall be used in all cases where testing of internal surfaces of enclosed or cylindrically shaped items of small diameter is required. A central conductor may also be used for circular magnetization of other shapes, when applicable. The conductors shall be as near the inside diameter as practicable. Items shall be spaced to avoid contact, and if warranted by the quantity of work involved, suitable fixtures shall be used for proper orientation.

4.3.2.5.4 Circular magnetization; item as conductor (direct method). Where it is necessary to pass current through the item, care shall be exercised to prevent arcing or overheating at the electrode contact areas. Contact areas shall be clean, items shall be mounted horizontally between contact plates, and suitable head pressure exerted to ensure uniform magnetization. When practicable, large and heavy items shall be mounted in suitable fixtures to ensure proper orientation. When protective coatings would interfere with the flow of current, they shall be removed at the area of contact. After tests, the coating shall be repaired.

4.3.2.5.5 Circular magnetization; magnetizing current. The magnetizing current required for an item depends on its shape, configuration, and size. The optimum current setting shall be determined by means of a segmented magnetic particle field indicator tested as specified in 4.3.1.8.

4.3.2.5.6 Longitudinal magnetization. When a solenoid is used to magnetize items, the solenoid shall be no larger than necessary to accommodate the item, and items shall be orientated within the solenoid to ensure adequate field strength.

4.3.2.5.7 Longitudinal magnetizing current. For longitudinal magnetization using a solenoid, the magnetizing force in ampere-turns should be determined in the following manner for general applications:

The ampere-turns used shall be 45,000/(L/D) (±10 %), where L is the length and D is the diameter of the part. The L/D ratio for parts being magnetized shall be two or more. Coils are usually effective in magnetizing the part for about 8 to 12 inches from each end of the coil. If longer parts are to be inspected, several magnetizing shots will be required. Either the inside or the outside diameter may be used depending on which surface is being inspected. When both surfaces are to be inspected, the larger diameter shall be used. A magnetic particle field indicator shall be used as specified in 4.3.1.8.

4.3.2.6 Maintenance of suspension. The suspension in use shall be tested for content of magnetic particles at intervals depending upon frequency of use, discoloration and contamination, but in any event not less than once each day. When the suspension becomes discolored by oil or contaminated with lint or other foreign material to the extent that proper distribution and concentration of the suspension or the intensity, character, or definition of the deposit of the magnetic particles are interfered with, the container shall be drained, thoroughly cleaned, and refilled with clean suspension.

4.3.2.6.1 Concentration of suspension test. The test method shall be determined by the organization. If for any reason the Government inspector doubts the adequacy of the method employed, he shall request the concentration to be checked by the following tests:

(a) Fill a standard 100-milliliter (mL) graduate to the 100 mL mark with the suspension directly from the hose or other device used for pouring it over the piece in making a test, or from an immersion tank after the suspension has been thoroughly agitated. Let the suspension stand for 30 minutes to precipitate, or until the solid matter is apparently all down.

(b) Decant the clean liquid as far as practicable without loss of magnetic substance.

(c) Refill graduate above magnetic substance with type II Stoddard Solvent in accordance with P-D-680 or acetone for water-base suspension. Shake well and let stand for 30 minutes to precipitate a second time.

(d) Read the height or volume of the precipitate in the graduate. The readings shall be as follows:

    (1) The nonfluorescent magnetic particles: 1.2 to 2.4 mL.
    (2) The fluorescent magnetic particles: 0.1 to 0.7 mL.

(e) If the concentration was checked daily, steps (b) and (c) may be omitted.

(f) For manufacturer-supplied aerosol cans, a certification statement from the manufacturer identifying the material by batch, and stating that it meets the concentration requirements of this specification, is an acceptable alternative to the above process.

4.3.3 Dry powder method.

4.3.3.1 General requirements for magnetic particles. The magnetic particles used for obtaining patterns of discontinuities shall be of a nontoxic, finely divided ferromagnetic material of high permeability and low retentivity, free from deleterious rust, grease, paint, dirt, or other material which might interfere with their proper functioning. Particles shall be of such size, shape and color as to provide adequate sensitivity and contrast for the intended use. All particles shall meet the requirements of AMS 3040.

4.3.3.2. Application and removal of particles. Dry magnetic particles shall be applied in such a manner that a light, uniform, dust-like coating settles upon the surface under test.

4.3.3.2.1. Removal of excess particles. Excess dry particles shall be removed by means of a dry air current of sufficient force to remove excess particles without removing relevant indications formed during powder application. Removal of excess particles shall comply with the procedure of 4.3.1.2 and must be accomplished while the magnetic field is applied to the item under test.

4.3.3.2.2. Automated equipment. Automatic powder blowers or any other form of forced air other than from a hand-held bulb shall not be used for the application or removal of dry magnetic particles unless specifically approved by NAVSEA.

4.3.3.3. Magnetizing procedures.

4.3.3.3.1. Circular magnetization. The method of magnetization and the magnetizing current shall be as specified in 4.3.2.5.3, 4.3.2.5.4, and 4.3.2.5.5, as applicable.

4.3.3.3.2. Longitudinal magnetization. The method of magnetization and the magnetizing current shall be as specified in 4.3.2.5.6 and 4.3.2.5.7.

4.3.3.3.3. Yoke magnetization. Yoke spacing of greater than 8 inches or less than 2 inches is not recommended. However, if yoke spacing of greater than 8 inches or less than 2 inches must be employed, the procedure must be qualified with the exact yoke spacing that is to be used. In complex or restrictive configurations, where the placement of yoke legs may be impractical, ac prods may be used in place of an ac yoke provided that the ac prods have been properly qualified and their use approved by NAVSEA.

4.3.3.3.4. Magnetizing current (prod methods). For prods, the magnetizing current, direct or rectified, shall be computed on the basis of 100 to 125 amperes per inch of prod spacing. Prod spacing of greater than 8 inches or less than 2 inches is not recommended. However, if prod spacing of greater than 8 inches or less than 2 inches must be employed, the procedure must be qualified with the exact prod spacing that is to be used.

4.3.3.4. Magnetizing technique (yoke and prod).

4.3.3.4.1. Weld inspection. The magnetic field shall be induced with the prods or yoke legs placed diagonally, 30 to 45 degrees, to the longitudinal axis of the weld, and repeating this test along the opposite diagonal of the weld. During inspection of adjacent areas of the weld, the prods or yoke legs shall overlap the previous placement by a minimum of 1 inch. As an alternative, the magnetic fields may be induced by placing the prods or yoke legs parallel to the longitudinal axis of the weld, overlapping the previous placement by a minimum of 1 inch. Subsequent to the longitudinal placement, the weld shall be inspected by placing the prods or yoke legs perpendicular to the weld. When this alternative is used, the area to be inspected shall be limited to one-fourth of the prod or yoke leg spacing on either side of a line joining the prods or yoke legs.

4.3.3.4.2. Base metal. Base metal shall be inspected using the prod and yoke leg placement requirements of 4.3.3.4.1 to establish a grid pattern that ensures two-directional coverage of inspection areas.

4.3.3.4.3. Continuous magnetization. During inspection, the magnetizing current shall remain on during the period the magnetic particles are being applied and while excess particles are being removed. For cases where the magnetic particles can fall off the item before the inspection is complete, the magnetizing current shall remain on during the examination of the inspection area, and the evaluation of any detected indications.

4.4. Evaluation of indications. When using either prods or yokes, any detected indications should be evaluated by moving the prods or yoke to the optimum magnetization position and re-applying the test. Prods should be placed parallel to the indication, yokes should be placed perpendicular to the indication.

4.5. Non-relevant indications. All indications revealed by magnetic particle inspection do not necessarily represent defects since non-relevant indications are sometimes encountered. Indications caused by marking methods such as scribe lines and vibro-etchings can be considered non-relevant unless the inspector has reason to believe that the marking is masking a relevant indication. If any other indications are believed to be non-relevant, the following methods may be used to prove non-relevancy:

(a) Not less than 10 percent of each type of indication shall be explored by removing the surface roughness believed to have caused the type of indication to determine if defects are present. The absence of indications under reinspection by magnetic particle inspection after removal of the surface roughness shall be considered to prove that the indications were non-relevant with respect to actual defects. If reinspection reveals any indications, these and all of the original indications shall be considered relevant.

(b) A liquid penetrant inspection after grinding to remove the surface roughness believed to have caused the indication.

(c) Other methods approved by the authorized NAVSEA representative.

4.6. Final cleaning. After completion of inspection, all magnetic particles shall be removed from all parts. All temporary plugs shall be removed from holes and cavities.

4.7. Arc strikes. For applications governed by a fabrication document, arc strikes shall be removed and reinspected as required in the fabrication document. For other applications the following shall apply: Arc strikes shall be ground out, faired into surrounding material, and reinspected using the prod or yoke method or visually inspected at not less than 5X magnification. Excavations and remaining wall thickness shall be inspected for and shall meet the requirements of the governing specification.

4.7.1. Arc strikes in high hardenability materials. For all arc strikes that occurred after final heat treatment in S-1 materials with carbon content greater than 0.30 percent, S-3, S-3A, S-4, S-5, S-6, and S-6A materials (as defined in MIL-STD-278), complete removal of the heat affected zone shall be verified with an etchant that has been demonstrated to disclose heat affected zone structure in the material involved unless repair welding is required. Etchants shall be prepared and used in accordance with good metallurgical practice.

5. LIQUID PENETRANT TESTING

5.1. Intended use. The liquid penetrant test method is used for detecting the presence of surface discontinuities in ferrous and nonferrous materials. Drawings specifying liquid penetrant testing shall employ nondestructive test symbols in accordance with AWS A2.4.

5.2. Definitions. The standard terminology for liquid penetrant examination as described in ASTM E 1316 shall apply to this section.

5.3. Inspection methods. The inspection method designation shall correspond to and use the material classifications specified in 5.3.1.

5.4. Liquid penetrant materials. Unless otherwise specified, liquid penetrant material shall meet the requirements of MIL-I-25135, and the total halogens and sulphur of each material shall be not greater than 1 percent by weight of the residue. The penetrant inspection materials are classified as follows:

Penetrant types:	Type I	- Fluorescent dye
	Type II	- Visible dye
	Type III	- Visible and fluorescent dye (dual mode)
Removal methods	Method A	- Water washable
	Method B	- Post emulsifiable, lipophilic
	Method C	- Solvent removable
	Method D	- Post emulsifiable, Hydrophilic
Sensitivity level:	Level 1/2	
	Level 1	- Low
	Level 2	- Medium
	Level 3	- High
	Level 4	- Ultrahigh
Development forms:	Form a	- Dry powder
	Form b	- Water soluble
	Form c	- Water suspendable
	Form d	- Nonaqueous
	Form e	- Specific application

5.4. General requirements. Penetrant testing shall be performed in accordance with a written procedure. Method C techniques shall not be used on threaded surfaces without approval of the NAVSEA authorized representative. Method A shall not be used for welds, except for casting inspections and weld repair to castings, unless specifically approved by NAVSEA.

5.4.1. Equipment requirements. The test equipment operated by qualified nondestructive test personnel shall be capable of consistently obtaining results of specified level of sensitivity.

5.4.2. Procedure. The liquid penetrant inspection procedures shall contain, as a minimum, the following information:

(a) Brand name and manufacturer's identifying designation of all materials used, as well as penetrant Type, removal Method, sensitivity Level (if applicable), and development Form.
(b) Details of method of precleaning and drying, including brand name and type of cleaning materials used, drying temperature requirements, and time allowed for drying.
(c) Details of method of penetrant application, the length of time that the penetrant remains on the surface, and the temperature of the surface and penetrant during penetration.
(d) Details of method of removing excess penetrant from the surface, and of drying the surface before applying the developer (where applicable).
(e) Details of the method of applying the developer and the length of developing time before inspection.
(f) Method of post-test cleaning.
(g) The applicable acceptance standards.

5.4.2.1. Change of penetrant materials. When the brand or type of precleaner, penetrant, penetrant remover (solvent), or developer differs from that specified in the procedure, a new procedure shall be prepared which includes all the information required by 5.4.2.

5.4.2.2. Record requirements. Records of liquid penetrant inspections shall contain the following:

(a) Description and unique identification of item inspected.
(b) Approved procedure identification.
(c) Penetrant manufacturer (brand) and Type identification.
(d) Acceptance standard used.
(e) Date of inspection.
(f) Signature(s) of inspector(s).
(g) Disposition (accept/reject) of the item inspected.

5.5. Surface preparation. Surfaces to be inspected shall be free from scale, slag and adhering or imbedded sand, or other extraneous materials. With the exception of undercuts which are within specification allowances, the contour of welds shall blend smoothly and gradually into the base metal. Weld surface irregularities shall be removed to the extent that they will not interfere with interpretation of the test results. The final liquid penetrant inspection shall be performed in the final surface condition as specified in 1.4 herein. Tumbling; peening; or shot, sand, grit, or vapor blasting shall not be performed on surfaces which are to be liquid penetrant inspected unless specifically approved by the authorized representative of NAVSEA.

5.5.1. Finished surfaces. Surfaces for which a specific finish is required shall be given such surface finish prior to the final liquid penetrant inspection prescribed by the applicable specifications. Inspection at intermediate stages of fabrication shall be as specified in the applicable specification.

5.6 Test procedures.

5.6.1. Order of testing. All liquid penetrant tests shall be performed prior to ultrasonic inspections on the same surfaces to avoid interference between the penetrant dye and any residual couplant. If liquid penetrant tests must be performed after ultrasonic inspection, this shall require special cleaning operations and approval of the activity's nondestructive test examiner on a case basis.

5.6.2. Pre-test cleanliness. Prior to liquid penetrant inspection, the surface to be tested shall be dry and free of dirt, grease, lint, scale and salts, coatings, or other extraneous matter that would obscure surface openings or otherwise interfere with the test. Any adjacent area within 1 inch of the surface to be tested shall be dry and free of any foreign material that might contaminate the dye or otherwise interfere with the inspection. All surfaces being tested shall be thoroughly cleaned of extraneous material. If a nonvolatile liquid is used for cleaning, the surface shall be heated or dried with hot air to assure complete removal of the cleaner. As a final cleaning operation each surface shall be dipped, sprayed, wiped, or brushed with, acetone, denatured ethanol (ethyl alcohol), isopropanol (isopropyl alcohol), or cleaner/removers supplied by penetrant manufacturers which meet the requirements of MIL-I-25135. Surfaces shall then be thoroughly dried by removing the excess with a clean dry cloth or absorbent paper, and allowing the remainder to evaporate for an appropriate drying time as follows:

Solution	Method of Application	Evaporation Time
Acetone	Any	5 minutes
Alcohol	Wiping with dampened cloth or absorbent paper	5 minutes
Alcohol	Other than wiping	20 minutes
Other	Any	As established (See below)

Other precleaners may be used for the final cleaning operation provided they meet the halogen and sulfur requirements of 5.3.1 and are qualified as follows: (Note that any precleaners qualified according to the following paragraphs shall only be used with the same air circulation (forced vs. natural) and temperature conditions used in the qualifying process.)

(a) The performance of the proposed cleaner and associated drying time/temperature combination shall be compared to the performance of acetone through the use of three MIL-I-25135 Type II penetrant system test panels (aluminum quench crack panels). The panels shall be soaked in an oil-based cutting fluid for twenty-four hours prior to the evaluation.

(b) The acceptability of the proposed precleaner and drying time/temperature combination shall be based on a comparison of the results obtained with the candidate procedure (using the minimum drying time/temperature combination (within 20 degrees Fahrenheit), and circulating air, if specified) versus acetone using a five minute drying time. All of the other procedure parameters shall be the same for the two trials. The minimum penetrant dwell time and the minimum development time allowed by the procedure shall be used. If, in the opinion of the Examiner, the indications obtained with the proposed precleaner and associated drying time/temperature combination are essentially the same as those obtained with the acetone, the precleaner and associated drying time/temperature is qualified for use.

(c) Documentation of the qualification shall include the signature of the Examiner and shall be provided to the Government inspector upon request.

5.6.3 Temperature. Maximum penetration into extremely small openings requires that the penetrant and the test surface be maintained at the temperature recommended by the penetrant manufacturer but shall be not less than 50 degrees Fahrenheit (°F). The temperature of the penetrant and the test surface shall be not greater than 100°F, except that for Type II Method C materials the temperature of the test surface may be a maximum of 150°F or the maximum temperature recommended by the manufacturer, whichever is less. Due to the flammable nature of liquid penetrant inspection materials, the use of an open flame for heating purposes shall be prohibited. Special conditions requiring deviation from the above requirement require approval by an authorized representative of NAVSEA.

5.6.4 Penetration time. The surface to be tested shall be thoroughly and uniformly coated with penetrant by flooding, brushing, immersion, or spraying, and shall be kept wetted throughout the penetration time, until the penetrant removal process begins. Any reduction in the liquid penetrant dwell time shall be specifically approved by NAVSEA. Unless prior approval has been obtained, the liquid penetrant dwell time shall be as follows:

Penetrant	Minimum penetration time (minutes)
Type II, Method C	15(1/)
Type II, Method B or D	15
Type II, Method A	25
Type I, Method A	25
Type I, Method B or D, Level 2	15
Type I, Method B or D, Level 4	10
Type I, Method C	15

1/ For Type II, Method C penetrants only, the minimum dwell time may be reduced to 5 minutes for surfaces not exposed to lubricants, machining oils, or cutting fluids during fabrication.

5.6.4.1 Application of emulsifier (Methods B and D). The emulsifier shall be applied in accordance with the manufacturer's instruction and as specified in 5.4.2.

5.6.5 Removal of penetrant.

5.6.5.1 Method C materials. The excess penetrant shall be removed from all surfaces as follows:

(a) As much excess penetrant as possible shall be removed by first wiping the surface thoroughly with a clean dry cloth or absorbent paper.

(b) The remaining excess penetrant shall be removed by wiping the surface with a clean cloth or absorbent paper dampened with a penetrant remover specified by the penetrant material manufacturer. (Note that for very smooth surfaces, the use of remover may not be necessary, and if used, could result in over cleaning.)

5.6.5.2 Surface flushing. Flushing of the surface with any liquid following application of the penetrant and prior to developing shall be prohibited.

5.6.5.3 Method B and D materials. Subsequent to completion of emulsification, the emulsifier shall be removed from the surface of the part by employing a warm water spray not greater than 120°F and 40 pounds per square inch (psi) pressure. After washing, items to be inspected using Type I materials shall be checked under a black light to ensure complete cleaning. Alternatively, the penetrant shall be removed by use of the cleaner specified by the manufacturer of the penetrant.

5.6.5.4 Method A only. The penetrant shall be removed from surfaces by swabbing with a clean lint-free cloth saturated with clear water or by spraying with water not greater than 120°F and 40 psig. After washing, items to be inspected using Type I materials shall be checked under a black light to ensure complete cleaning.

5.6.6 Surface drying.

5.6.6.1 Method C . The drying of test surfaces after the removal of the excess penetrant shall be accomplished only by normal evaporation, or by blotting with absorbent paper or clean, lint-free cloth. Forced air circulation in excess of normal ventilation in the inspection area shall not be used. Unless otherwise specified by the penetrant manufacturer, the time for surface drying after removal of excess penetrant and prior to application of the developer shall be not greater than 10 minutes.

5.6.6.2 Methods A, B, and D. The drying of test surfaces shall be accomplished by using hot-air recirculating ovens, circulating air, blotting with paper towels or clean lint-free cloth, or by normal evaporation. If a drying oven is used, the temperature shall not exceed 160°F. It is important that during the drying operation, no contaminating material be introduced onto the surface which may cause misinterpretation during the inspection operation. The time for surface drying operation shall be in accordance with the manufacturer's instructions.

5.6.7 Application of developer.

5.6.7.1 Nonaqueous wet developer. For Method C liquid penetrant inspections, only a nonaqueous wet developer specified by the penetrant manufacturer shall be used, and shall be applied only to dry surfaces. Immediately prior to application the developing liquid shall be kept agitated in order to prevent settling of solid particles dispersed in the liquid. The developer shall be uniformly applied in a thin coating to the test surface by spraying. If the geometry of the item being inspected precludes the use of a spray, a brush or similar applicator shall be used provided it results in a uniform, thin coating of developer. Pools of wet developer in cavities on the inspection surface shall not be permitted since these pools will dry to an excessively heavy coating in such areas resulting in the masking of indications. Inspection shall be made not less than 7 minutes and not greater than 30 minutes after the developer has dried.

5.6.7.2 Dry developer. Dry developing powder shall be applied only on dry surfaces so that matting will be prevented. The powder shall be thinly but uniformly applied to provide a dusty appearance immediately after drying of the test surface. Time for development of indications after the developing powder has been applied shall be not less than 10 minutes and not greater than 30 minutes.

5.6.7.3 Aqueous wet developer. This type of developer shall be uniformly applied to surfaces by dipping, spraying, or brushing as soon as possible after removal of all excess penetrant but in no case to exceed 10 minutes. The surface may be dried prior to the application of the aqueous wet developer, but this is not necessary. When using liquid-type developers, it is necessary that they be continually agitated in order to prevent settling of solid particles dispersed in the liquid. Concentrations of wet developer in cavities on the inspection surface shall not be permitted since these pools will dry to an excessively heavy coating in such areas resulting in the masking of indications.

5.6.8 Lighting in test area. When using the visible dye penetrant inspection, the test area shall be adequately illuminated for proper evaluation of indications revealed on the test surface. When fluorescent penetrant is used, the inspection shall be accomplished in a darkened area using a black light (ultraviolet light). The black light shall be capable of producing an intensity of 800 micro-watts per square centimeter on the inspection surface. Intensity shall be measured daily, and after bulb replacement. Not less than 5 minutes shall be allowed for the lamp to obtain full brilliance before beginning the inspection.

5.6.9 Final cleaning. When the inspection is concluded, the penetrant materials shall be removed as soon as possible by means of water or solvents as specified in 5.6.2 and with applicable cleaning specifications.

5.6.10 Safety precautions. Penetrant inspection materials shall be used in accordance with all applicable safety regulations.

5.7 Test results.

5.7.1 Determination of relevancy. All indications in weld craters shall be considered relevant and shall be evaluated in accordance with the applicable acceptance standards. Indications caused by marking methods such as scribe lines and vibro-etchings can be considered non-relevant unless the inspector has reason to believe that the marking is masking a relevant indication. For other indications which are believed to be non-relevant, the following methods may be used to prove non-relevancy.

(a) Not less than 10 percent of each type of indication shall be explored by removing the surface condition believed to have caused the indications and retested. The absence of indications under reinspection by liquid penetrant after removal of the surface condition shall be considered to prove that the indications were non-relevant with respect to actual defects. If reinspection reveals any indications, these and all of the original indications shall be considered relevant.

(b) Other methods when approved by the Government inspector.

6. ULTRASONIC TESTING

6.1 Intended use. The ultrasonic test method is used for the detection of discontinuities throughout the volume of material, measurement of wall thickness, and evaluation of bond characteristics in most types of material and in basic geometric configurations.

6.2 Definitions. The standard terminology for ultrasonic examination as described in ASTM E 1316 shall apply to this section, except as noted below.

6.2.1 Acoustically similar materials. The same type of material as that to be inspected or another material which has been experimentally proven to have an acoustical velocity within plus or minus 3 percent for thickness testing, and for amplitude comparison test the back reflection amplitude from equal thicknesses shall be within plus or minus 1 dB (or 10 percent) of each other as measured on the instrument display. This test shall be conducted on samples having equal contour and surface finish for both the sound entrant and reflective surfaces.

6.2.2 Amplitude rejection level (ARL). The horizontal level on the instrument display which is established as either a percentage of full scale height or as a decibel (dB) level based on the peak amplitude of the signal received from the applicable reflective surface in the calibration standard.

6.2.3 As-welded condition. The condition of weld metal, welded joints, and weldments after welding and removal of slag, spatter, and so forth, prior to any thermal or mechanical treatment.

6.2.4 Calibration. Adjustment of the ultrasonic system to give desired indication height and position from known reflecting standards as required for the inspection being performed.

6.2.5 Calibration reflectors. Ultrasonic reflectors, such as a side-drilled hole, flat-bottomed hole, or notch, that are permitted by applicable documents to be used for calibration.

6.2.6 Calibration standard. See reference calibration standard.

6.2.7 Class of weld. Weld classes I, II, and III are used to differentiate between critical and less critical welds and relate to acceptance criteria. Weld classes are defined by applicable fabrication documents.

6.2.8 Continuous scan. A scanning practice in which each pass with the transducer overlaps the previous pass by not less than 25 percent.

6.2.9 Disregard level (DRL). The horizontal level on the instrument display established at a given level below the amplitude rejection level (ARL).

6.2.10 Full screen height. The highest point on the instrument display used for evaluation and recording purposes, designated as 100 percent or scale 10.

6.2.11 IIW block. A standard test block designed by the International Institute of Welding (IIW) to check the operation of the ultrasonic system and search units or transducers.

6.2.12 Instrument display. Device used to show results of the ultrasonic examination. Can be cathode ray tube (CRT), liquid crystal screen, segmented digital display, or other appropriate device.

6.2.13 Peak indication. The maximum height or amplitude of an indication received from any one reflective surface using a constant gain setting.

6.2.14 Reference calibration standard. A sample of material acoustically similar to the material to be tested containing known reflectors with which the ultrasonic system is calibrated and acceptance/rejection levels established.

6.2.15 Ultrasonic test sensitivity. The sensitivity at which the test will be conducted.

6.2.16 Ultrasonically sound material. A material which is capable of exhibiting an 80 percent of full scale reflected signal amplitude from a specified reflector with no more than 20 percent of full scale extraneous signal amplitude (noise).

6.3 Procedure and test methods. The test methods which follow apply to the inspection of forgings, castings, rolled or extruded shapes, bar stock, plate, weldments, pipe and tubing, bonded materials, and metal sheet. As described herein, the procedures are largely manual. Automation, however, may be applied to these methods when it serves to minimize operator induced variables. This relates only to testing, not to analysis. Computer-assisted analysis in any form requires specific NAVSEA approval. Traditional C-scans and B-scans produced by direct-drive pens, and conventional ultrasonic instruments using "gates" are not considered to be computer-assisted. Neither are such devices as "digital thickness gauges" or "data loggers." All other systems which produce "images," or which make inferences or draw conclusions based on the ultrasonic signals, are considered to be computer-assisted and require certification. Testing can be performed more easily and reproducibly on parts which have the simple geometries associated with early stages of fabrication. Inspection methods other than those specified in this section may be used, provided approval is based on procedural qualification obtained from the authorized NAVSEA representative. All tests shall be performed in accordance with a written inspection procedure approved as specified in 1.7.

6.3.1 Test method selection. The method or methods required for inspection of a component is specified by the equipment or material specification or other fabrication document. Selection of a test method or combination of methods shall be based upon the configuration and the orientation of expected discontinuities in the items to be inspected.

6.3.2 Surface finish. Surfaces of material to be inspected shall be clean and free of dirt, loose scale, loose paint, or other loose foreign matter. Surfaces to be inspected shall have a finish of not greater than 250 ra (microinches) and be free from waviness that may interfere with the test. Unless specifically permitted, the surface finish of the calibration standard shall not be any smoother than that of the material to be tested.

6.3.3 Testing speed. Rotation or speed of the part or search unit shall be controlled as closely as possible and shall be consistent with operator readout capability. In any case, the test speed shall be not greater than the maximum speed at which the calibration standard can be scanned to produce a clearly resolved indication.

6.3.4 Couplant. A couplant shall be used which causes acoustic coupling between the transducer and the part being inspected. This couplant shall not be injurious to the material. Glycerin or glycerin mixed with water or alcohol are some materials which may be used as a couplant. The couplant shall be removed from the part at the completion of the inspection.

6.3.5 Test symbols. Drawings specifying ultrasonic inspection shall employ symbols in accordance with AWS A2.4.

6.3.6 Calibration. Prior to any inspection, the equipment shall be calibrated, using the proper calibration standard, and shall be rechecked no less than once per 8-hour shift, and at the completion of testing. If the recheck indicates that instrument sensitivity has dropped by more than 1 db, all items tested since the last instrument check shall be reinspected. During testing, any realignment of the search unit or any change in search unit, instrument settings or scanning speed from that used for calibration shall require recalibration. (Note: For thickness measurement only, the gain setting may be modified without requiring recalibration.)

6.4 Equipment. The instrument and accessory equipment shall be capable of generating, receiving, amplifying, and displaying electrical pulses at frequencies and pulse rates necessary for the intended inspection.

6.5 General requirements.

6.5.1 Equipment requirements.

6.5.1.1 Basic instrument qualification - A-scan display instruments. A single transducer shall be used to perform all of the instrument qualification operations of paragraphs 6.5.1.1.1, 6.5.1.1.2, 6.5.1.1.3, and 6.5.1.1.4.

6.5.1.1.1 Vertical linearity. The vertical linearity shall be within plus or minus 10 percent (in the range between 20 percent and 80 percent of full screen height) as measured in accordance with ASTM E 317 or other approved method. Instrument settings used during inspection shall not cause variation outside the 10 percent limits established above.

6.5.1.1.2 Horizontal linearity. When the time-distance relationship (horizontal linearity) displayed on the sweep of the instrument display is a function of the test, the horizontal linearity shall be within plus or minus 3 percent, as measured in accordance with ASTM E 317 or other approved method.

6.5.1.1.3 Resolution. The system shall be capable of resolving the calibration holes within the range of material thickness to be inspected using the calibration block(s) specified, as described in ASTM E 317, or other approved method.

6.5.1.1.4 Attenuation. A calibrated gain or attenuator control, if used in a procedure, shall be evaluated according to the requirements of ASTM E 317, or by converting dB to an amplitude ratio using the relationship:

$$\text{Amplitude Ratio} = \log_{10}^{-1}(dB/20)$$

The calibrated gain or attenuator shall be accurate to plus or minus 20 percent of the nominal amplitude ratio at the inspection frequency and range.

6.5.1.2 Shear wave transducer. Shear wave search units shall have a refracted angle within the limits of plus or minus 3 degrees of the designated angle at 68°F ± 10°F, as determined by an IIW or similar block.

6.5.1.3 Basic instrument qualification - thickness gauge. Not less than two readings shall be made on each of a series of test blocks representative of the ranges of the instrument. Variations between the true thickness and the determined thickness shall be reduced to plus or minus percentage variation. A sufficient number of readings shall be made to accurately determine the thickness testing characteristics of the instruments. Not less than 95 percent of the total number of readings shall be within plus or minus 3 percent of the true value. For thicknesses of not greater than or equal to 0.150 inch, the readings shall be within plus or minus 0.005 inch of the true value.

6.5.1.4 Frequency of basic instrument qualification. The basic instrument qualification shall be performed and documented at intervals not greater than 6 months or whenever maintenance is performed which affects the equipment function.

6.5.2 Inspection procedure. The ultrasonic inspection procedures shall contain, as a minimum, the following information:

(a) Materials, shapes, or sizes to be tested or to be exempt from test.
(b) Automatic defect alarm and recording equipment or both.
(c) Special search units, wedges, shoes, or saddles.
(d) Rotating, revolving feeding mechanisms.
(e) Stage of manufacture when test will be made.
(f) The surface from which the test shall be performed.
(g) Surface finish.
(h) Couplant.
(i) Description of the calibration method.
(j) Scanning (for welds, include specific requirements to ensure complete coverage of the required inspection zone).
(k) Mode of transmission.
(l) Transducer size and frequency, and angle, if applicable.
(m) Acceptance standards.
(n) Method of recording inspection results.

6.5.2.1 Procedure requalification. Changes to the ultrasonic inspection procedure within the scope of this section that affects the technical aspect of the procedure shall be approved by the ultrasonic test examiner prior to use. Changes outside the parameters of this section or a change to a material that is not acoustically similar to that for which the procedure has been qualified shall require requalification of the procedure.

6.5.3. Discontinuity evaluation. If discontinuities are detected, the search unit shall be directed to maximize the signal amplitude from the discontinuity for evaluation.

6.5.4. Records. Records of ultrasonic inspection shall contain the following:

(a) Description and unique identification.
(b) Approved procedure identification.
(c) Instrument manufacturer, model number, and serial number
(d) Transducer size and type.
(e) Search beam angle.
(f) Test frequency.
(g) Couplant.
(h) Calibration standard number.
(i) Acceptance standard used.
(j) Date of inspection.
(k) Signature(s) of inspector(s).
(l) Disposition (accept/reject) of the item inspected.

6.6 Test methods.

6.6.1. Forged, wrought, and extruded material. Tests of forgings, wrought bars, and extruded material shall be made at the same frequency used to calibrate the equipment. Controls shall be set during the calibration and shall not be changed during the production test.

6.6.1.1. Test calibration, longitudinal wave. Unless otherwise specified, when testing forgings, including ring, rectangular rounded, multi-sided disc or pancake and all wrought bars using longitudinal waves, the calibration criteria of table VI shall apply.

6.6.1.2. Ring forgings.

6.6.1.2.1. Test calibration, shear wave. The calibration standard for ring forgings with wall thicknesses not greater than 20 percent of the outside diameter shall have two notches cut axially, one on the inside surface and one on the outside surface of the test standard. They shall be located so that their sides are smooth and parallel to the axis of the forging and that readily distinguishable individual ultrasonic indications are obtained from each notch. Shear wave inspection shall be performed at 3 percent notch sensitivity. The dimensions of the notch shall comply with table VII, except that available V-shaped calibration notches that were fabricated to meet the requirements of MIL-STD-2132 are acceptable for use. Scan until the notch indication from the inside diameter appears at the farthest position to the left at which it is readable. Move the search unit away from the inside diameter notch until the indication from this notch reappears along the horizontal trace. Mark these two positions on the face of the scope. Scan until the notch indication from the outside diameter is produced at maximum amplitude between these two marks. The amplitude of this notch indication shall be marked on the face of the scope. When the test instrument incorporates distance-amplitude controls it is recommended that they be used where possible to equalize these indication amplitudes to form an ARL of not less than 50 percent of full screen height. If this is not possible, or if the instrument is not equipped with a distance amplitude correction circuit, a distance amplitude curve shall be constructed on the screen with the lowest point at not less than 20 percent full screen height. Ring forgings with wall thicknesses exceeding 20 percent of their diameters cannot be inspected by circumferential shear wave scan where both inside and outside notches must be monitored. Alternate ultrasonic inspection methods for these forgings shall be specified.

6.6.1.2.2. Test. The entire outer surface shall be scanned circumferentially using the continuous scanning method. Unless otherwise specified, the test shall be performed in two opposing directions. Size and locations of indications in excess of that received from the calibration notches in accordance with table VII shall be marked on the material.

Table VI Calibration hole size for longitudinal test

Section thickness (inches)	Diameter of flat bottomed hole (FBH) (inches ± 0.005)
Less than 1/2	1/32
1/2 to less than 1-1/2	1/16
1-1/2 to less than 2-1/2	3/32
2-1/2 to less than 3-1/2	1/8
3-1/2 to less than 4-1/2	5/32
4-1/2 to less than 5-1/2	3/16
5-1/2 to less then 6-1/2	7/32
6-1/2 and over	1/4

NOTES:

1. **All flat bottomed holes shall have bottoms parallel to the entrant or to the tangent of the entrant surface.**
2. **The calibration standard shall be wide enough to permit sound transmission to the flat bottomed hole without side effects.**
3. **The calibration standard material shall be acoustically similar and within 1/8 inch of the material thickness to be inspected and shall be ultrasonically sound. The surface finish and curvature shall be similar to the test surface.**
4. **Flat bottomed holes for test standards shall be drilled to a depth of one-half the thickness or 1 inch whichever is less.**
5. **The test frequency shall be the same as the calibration frequency.**
6. **The couplant used for calibration shall be the same as that used for inspection.**
7. **The use of distance amplitude correction curves is permitted for calibration.**

TABLE VII Calibration reference notch dimensions of square and "U" bottom notch

Depth (percent of thickness)	3 ±1/2 percent or 0.005 ±0.0005 inch whichever is greater
Width Length	2 X depth (approximate) 1 inch (minimum)

6.6.1.2.3 Longitudinal wave tests of ring forgings.

6.6.1.2.3.1. Test calibration, longitudinal wave. Sound transmission into the ring shall be confirmed by observing the first back reflection obtained from the ring. Sensitivity of the instrument shall be adjusted until the indication from the flat bottomed hole in the standard is 80 percent of full screen height. The calibration standard shall conform to the requirements of table VI.

6.6.1.2.3.2. Testing - longitudinal wave. The ring shall be tested using the continuous method by directing the sound beam radially and axially. The

axial beam direction scan shall be performed when not restricted by configuration or geometry of the material under test. The first back reflection shall be positioned on the screen to verify sound transmission and any defect indication shall appear between the initial pulse and the first back reflection.

6.6.1.3 Rectangular forgings.

6.6.1.3.1 Test calibration, longitudinal wave. Sound transmission into the forging shall be confirmed by observing the first back reflection obtained from the forging. Sensitivity of the instrument shall be adjusted until the indication from the specified reference calibration standard is at 80 percent of full screen height. The reference standard shall conform to the requirements of table VI.

6.6.1.3.2 Testing - longitudinal wave. Rectangular forgings shall be tested using the continuous scanning method on surfaces such that three major planes shall be covered. Scanning with the sound beam directed axially shall be performed when not restricted by configuration or geometry of the material under test. The first back reflection shall be positioned on the screen to verify sound transmission. Suspect areas disclosed under these conditions shall be further evaluated from the side opposite to that which was originally inspected to determine maximum flaw signal amplitude.

6.6.1.4 Round and multi-sided forged or wrought bars including disc or pancake forgings.

6.6.1.4.1 Test calibration, longitudinal wave. Sound transmission into the forging shall be confirmed by observing the first back reflection obtained from the forging. Sensitivity of the instrument shall be adjusted until the indication from the specified reference calibration standard is at 80 percent of full screen height. The reference standard shall conform to the requirements of table VI.

6.6.1.4.2 Testing - longitudinal wave. Each bar or forging shall be tested using the continuous scanning method on surfaces such that all major planes shall be covered. For bars, scanning with the sound beam directed axially shall be performed only when specified.

6.6.2 Plate and sheet.

6.6.2.1 Surface preparation. The test surface shall be free of all loose dirt, rust or any foreign substance which may interfere with the test. The surfaces may have one coat of primer.

6.6.2.2 Shear wave testing technique. Shear wave testing shall be performed only when specified.

6.6.2.2.1 Test calibration. When specified, shear wave inspection shall be performed to a 3-percent notch sensitivity. Using any suitable means, a calibration reference notch shall be formed in the test surface of the plate being inspected or acoustically similar test piece. An angle beam search unit, capable of transmitting a shear wave at an angle of 45 degrees in the material being tested, and a frequency of 2.25 MHz shall be used. The instrument shall be adjusted to display signals from the reference notch specified in table VII at one-half and full skip distance. The amplitude of the reflected signal from the reference standard at the half skip distance shall be adjusted to 80 percent of full screen height. The amplitude of the signal from the reference standard at full skip distance shall be marked on the viewing screen. A line shall be drawn from the peak signal at half skip to the peak signal at full skip distance. Flaws in the plate or sheet being inspected shall be evaluated to the test sensitivity as established by this line.

6.6.2.2.2 Grid test procedure. When grid shear wave testing is specified, it shall be performed by scanning one major surface in two directions, causing the sound beam to travel parallel to and perpendicular to the longitudinal axis or direction of rolling of the plate. In the case of square cross rolled plate, either direction is acceptable. The search unit shall be moved in parallel paths on a 6-inch grid. If an indication is obtained which has an amplitude of 50 percent or greater of that established in 6.6.2.2.1, the adjacent area shall be scanned by the continuous scanning method sufficiently to establish the size and location of the discontinuity.

6.6.2.2.3 Continuous scanning procedure. When continuous shear wave testing is specified, it shall be performed by continuously scanning one major surface completely in two directions, causing the sound beam to travel parallel to, and perpendicular to the longitudinal axis or direction of rolling of the plate. The search unit shall be moved in parallel paths to accomplish continuous scanning until the entire dimension is traversed. Either full skip or 1-1/2 skip shall be used to insure that both upper and lower surfaces and the entire interior volume are interrogated.

6.6.2.3 Longitudinal wave testing technique.

6.6.2.3.1 Testing calibration. A compressional wave search unit having a dimension of 1 inch square or 1 inch in diameter, operating at a frequency of 2.25 MHz, unless otherwise specified, shall be placed on a defect free area. (A defect free area is defined as an area which has been evaluated at the highest ultrasonic sensitivity applicable for the test.) The ultrasonic instrument gain shall be adjusted to display the first back reflection at full screen height. This sensitivity level shall be used to evaluate the plate.

6.6.2.3.2 Test procedures.

6.6.2.3.2.1 Continuous method. Continuous scan method testing shall be performed by scanning one major surface 100 percent, only when specified.

6.6.2.3.2.2 Static method. Testing shall be performed by interpreting the instrument display when the search unit has been statically placed at each intersecting grid line on one major surface of the plate. The grid pattern shall consist of not greater than 2-foot squares for all plate and sheet over 1/2 inch to and including 2-1/2 inches thick. For plates over 2-1/2 inches, the grid pattern shall be 8 inches square. Grid patterns as specified herein shall prevail unless modified by the contract, order, or material specification. If an unacceptable indication is obtained, the adjacent area shall be scanned in a 1-foot radius circle by the continuous method to determine the extent and magnitude of the defective condition.

6.6.3 Pipes and tubes.

6.6.3.1 Scanning technique. Pipe and tube shall be tested, using the continuous scan method as specified in 6.6.1.2.2 for radial type discontinuities extending longitudinally. Transverse discontinuity tests and additional circular tests shall be performed only when and as specified. When specifically invoked, 6.6.1.1 shall apply.

6.6.3.2 Test calibration, radial defects detection. Select a length of pipe or tube of acoustically similar and ultrasonically sound material and the same nominal size as the pipe or tube to be tested for use as a calibration standard. For calibration in testing for radial defects, two notches shall be cut; one on the inside surface and one on the outside surface as specified in 6.6.1.2.1. The notches shall be located approximately 1-1/2 inches from one end of sample. The notch shall be cut in such a manner that its sides are smooth, radial and extend parallel to each other and to the longitudinal axis of the pipe or tube. Magnitude of the indication for the notches shall be determined by directing sound waves circumferentially toward the notches with the search unit located at a suitable radial arc displacement using not less than one full skip technique where possible (see figure 17). If the indications from the inside and outside notches are unequal, small adjustments shall be made in the angle of incidence to equalize them. If the indications cannot be equalized, the smaller indication shall be used as the basis for evaluation.

6.6.3.3 Test, radial defects. When testing pipe and tubes, they shall be set with the longitudinal axis in a horizontal position on motorized rollers or other suitable mounting which shall permit rotation of the pipe or tube about the longitudinal axis. Rotation shall be controlled at a fairly uniform speed, depending upon the repetition rates established for the test unit being employed. In any case, the peripheral speed shall be not greater than the maximum speed at which the calibration standard is rotated for clear definite resolution of the notch being presented. When the immersion method is used, the test conditions shall duplicate calibration conditions especially in regard to keeping the tube bore filled or dry during test. In general, excluding the immersion fluid from the tube bore improves the reproducibility of test results.

6.6.4 Ultrasonic inspection of weldments.

6.6.4.1 Scope. This section contains the minimum requirements for the inspection of structural butt, corner, and tee welds to ensure joint integrity as required by specifications, contracts and acquisition documents.

6.6.4.2 General requirements.

6.6.4.2.1 Scanning. Scanning shall be as required to ensure complete coverage of the inspection zone (see figures 18, 22, 23, 26, 27 and 28). If full coverage is not possible due to configuration, accessibility or base metal discontinuity, actual coverage shall be recorded and the reason noted for incomplete coverage. For the volumetric inspection of butt, corner, and tee welds, the sound beam shall cover the inspection zone with a crossing pattern. If only one directional coverage of the inspection zone is possible due to configuration, accessibility, or base metal discontinuity, actual coverage and the reason for one directional coverage shall be recorded.

6.6.4.2.2 Surface finish. Welds may be inspected in the as-welded condition, provided the required test sensitivity and inspection coverage can be maintained. The weld reinforcement shall be ground flush to provide a flat surface when ultrasonic inspection is to be accomplished by scanning on the weld surface. The test surface may have one coat of primer.

6.6.4.2.3 Limitations. The requirements of this section were developed for the inspection of welded joints in ship hull structures. These joints consist of butt, corner, and tee design in HY-80, HTS and similar materials in thicknesses ranging from 1/4 inch and up. The use of these requirements on other materials, other thicknesses, or other joint designs shall be reviewed for applicability of test sensitivity and technique by the examiner and demonstrated to the NAVSEA authorized representative.

6.6.4.2.4 Reference calibration standards.

6.6.4.2.4.1 Butt welds, corner welds, tee welds for discontinuities into the through member, and tee weld volumetric inspection. The calibration standards shall be acoustically similar material as that to be inspected, and shall be ultrasonically sound. They shall be capable of providing constant reference sensitivity levels for all angles of search and inspection depth. The standard reflecting surface shall be a 3/64-inch diameter hole drilled through a 1-1/4 inch wide block. The surface of the test block shall be approximately 125 ra (microinches) as compared to surface finish standards. See figure 19 for a typical reference calibration standard. An additional 3/64 inch diameter calibration hole at a depth of 1/8 inch shall be added to the standard for the inspection of flush ground welds with thicknesses less than 1/2 inch.

6.6.4.2.4.2 Detection of lack of penetration in full penetration tee welds. The calibration standard shall be the through member upon which the inspection is being performed.

6.6.4.3 Specific requirements for butt and corner welds and the volumetric inspection of tee welds.

6.6.4.3.1 Instrument. The instrument shall have circuitry to provide a continuously increasing amplification with respect to time. This circuitry compensates for the signal losses with depth as a result of sound beam divergence and its attenuation in material.

6.6.4.3.2 Transducers. The maximum dimension of the transducer's active element shall be not greater than:

(a) 1/2 inch for plate thicknesses less than 1/2 inch.
(b) 1 inch for plate thicknesses equal to or greater than 1/2 inch.

The nominal frequency shall be not less than:

(a) 4.0 MHz for plate thicknesses less than 1/2 inch.
(b) 2.0 MHz for plate thicknesses equal to or greater than 1/2 inch.

The transducers used for shear wave inspections shall be affixed to suitable wedges designed to induce shear waves in the material at the following recommended angles. The beam angle should be based on the thickness of the plate as follows:

(a) For plate thicknesses 1/4 to, but not including, 1/2 inch: a 70-degree angle.

(b) For plate thicknesses 1/2 inch to, but not including, 1-1/2 inches: a 60 to 70-degree angle.

(c) For plate thicknesses 1-1/2 inches to, but not including 2-1/2 inches: a 45 to 60-degree angle.

(d) For plate thicknesses 2-1/2 inch and over, a 45-degree angle.

(e) For tee weld volumetric scanning from the through member, a 45° shear wave.

Additional angles may be used to complement the primary transducer to obtain 100% coverage when otherwise precluded by configuration, or for the detection and/or evaluation of discontinuities.

6.6.4.3.3 Calibration. The instrument range and delay controls shall be adjusted to display signals from the reference calibration holes on the viewing screen for the range of depths to be inspected. The attenuation-correction controls shall be adjusted to compensate for the signal losses due to depth.

6.6.4.3.3.1 Class I welds. When a decibel control is used, the instrument gain shall be adjusted to peak all signals from the reference calibration holes within the range of the test at not less than 20 percent of full screen height. The corresponding depth and location of the peaked signals from the reference calibration standard shall be marked along the base line of the viewing screen. The gain shall be increased by 12 dB. At this gain setting, the line established by the original signal height on the viewing screen is the DRL and the ARL is 12 dB above this line. For evaluation of indications above the DRL, the dB control is used (see figure 20). When a dB control is not used, the instrument gain shall be adjusted to peak all signals within the range of test at not less than 80 percent of full screen. The corresponding depth and location of the peaked signals from the reference calibration standard shall be marked along the base line of the viewing screen. The screen shall be divided by two horizontal lines at 20 percent (the DRL) and 80 percent (the ARL) of full screen height (see figure 21).

6.6.4.3.3.2 Class II and III welds. When a dB control is used; the instrument gain shall be adjusted to peak all signals from the reference calibration holes within the range of test at not less than 40 percent of full screen height. The corresponding depth and location of the peaked signals from the reference calibration standard shall be marked along the base line of the viewing screen. The gain shall be increased 6 dB. At this gain setting, the 40 percent line on the viewing screen is the DRL, and the ARL is 6 dB above this line. For evaluation of indications above the DRL, the dB control is used. When a decibel control is not used, the instrument gain shall be adjusted to peak all signals within the range of test at not less than 80 percent of full screen. The corresponding depth and location of the peaked signals from the reference calibration standard shall be marked along the base line of the viewing screen. The screen shall be divided by two horizontal lines at 40 percent (the DRL) and 80 percent (the ARL) of full screen height.

6.6.4.3.4 Procedure. The entire weld volume (excluding the weld reinforcement for butt and corner welds) and heat affected zone (up to 1/2 inch of base metal) is the inspection zone and shall be scanned with shear waves by directing the sound beam toward, or across, and along the weld axis.

6.6.4.3.4.1 Longitudinal discontinuities. To detect longitudinal discontinuities, the axis of the sound beam shall traverse the inspection zone in two opposing directions (see figures 22 and 28). For welds where two-directional scanning is impracticable, a minimum of one-direction scanning may be approved by the examiner on a case basis. The search unit shall be oscillated to the left and right with an included angle of approximately 30 degrees in a radial motion while continuously scanning perpendicularly toward and away from the weld.

6.6.4.3.4.2 Transverse discontinuities. To detect transverse discontinuities for welds not ground flush, the sound unit shall be placed on the base metal surface at the weld edge. The sound beam shall be directed by angling the search unit approximately 15 degrees toward the weld from the longitudinal weld axis. Scanning shall be performed by moving the search unit along the weld edge from both sides on one surface and from two opposing directions. To detect transverse discontinuities for welds ground flush, the search unit shall be oscillated to the left and right, with an included angle of approximately 30 degrees in a radial motion, while scanning along the top of the weld from two opposing directions. If the weld width exceeds the width of the transducer, continuous scanning shall be performed. Note - for the detection of transverse discontinuities in tee weld volumetric inspection, scanning shall be from the through member surface when accessible. This scanning shall be the same as required for butt welds ground flush. If the through member is not accessible, scanning shall be as required for as-welded butt welds.

6.6.4.3.4.3 Compressional wave. If compressional wave testing is employed, calibration shall be accomplished as specified in 6.6.4.3.3 with reference calibration standards as specified in 6.6.4.2.4. The weld shall be scanned continuously.

6.6.4.3.4.4 Discontinuity evaluation. If discontinuities are detected, the sound beam shall be directed to maximize the signal amplitude. To determine the length of a discontinuity, the search unit shall be moved parallel to the discontinuity axis in both directions from the position of maximum signal amplitude. One half the amplitude from a point where the discontinuity signal drops rapidly to the baseline shall be defined as the extremity of the discontinuity. At this point, the scanning surface is marked at the position indicated by the center of the transducer. This shall be repeated to determine the other extremity. Irrespective of the height of the DRL, when the half amplitude signal from the end of the discontinuity as determined by this method is below 20 percent of full screen height, the end of the discontinuity shall be defined where the signal crosses 20 percent of full screen height. The length of the discontinuity shall be defined as the distance between these two marks. The maximum signal amplitude, length, depth, and position within the inspection zone shall be determined and reported for discontinuities yielding a signal amplitude equal to or exceeding the DRL.

6.6.4.3.5 Transverse discontinuities (special case). This procedure shall be used only when specifically invoked. To detect transverse discontinuities, welds shall be in a flush ground or flat-topped (not less than 75 percent of the width of the weld bead) condition, sufficient to permit adequate sound penetration into the weld. A decibel control ultrasonic instrument shall be used. Instrument gain shall be increased over the normal calibration level by 6 db. Scanning shall be performed as specified in 6.6.4.3.4.2, but with the following modifications: Transducer shall be 2.25 MHz, 60-degree angle (45-degree for material thickness greater than 3 inches), with an element size of not greater than 1/2 inch. For the detection of transverse discontinuities, the indication amplitude must equal or exceed 20 percent screen height while maintaining the transducer orientation within ±15° of the weld axis. Any indication detected during this scan shall be further evaluated by turning the transducer and scanning as specified in 6.6.4.3.4.1. If this further evaluation does not detect the same indication at a level which equals or exceeds 20 percent screen height, then the indication shall be classified as a suspected transverse crack. Suspected transverse cracks shall be sized for vertical height as specified in 6.6.4.4.2.4 (a) through (c).

6.6.4.4 Specific requirements for welds of tee joints.

6.6.4.4.1 Detection of lack of penetration in full penetration tee welds. This section specifies the procedures to be used for the ultrasonic inspection of tee welds for discontinuities in the root area. The depth of the inspection zone shall be limited to through member plate thickness plus 1/4 inch minus 1/8 inch. The width of the inspection zone shall be limited to the thickness of the attachment member (see figure 23). The inspection shall employ the pulse-echo compressional wave testing technique.

6.6.4.4.1.1 Search units. The size of the transducer used for inspection shall be not greater than 3/4 inch diameter; however, it shall be not greater than the thickness of the attachment member. The inspection frequency shall be not less than 2.0 MHz.

6.6.4.4.1.2 Calibration. The instrument range and delay controls shall be adjusted to discriminate and indicate signals on the viewing screen from the inspection zone. The sweep line shall be marked indicating through member plate thickness minus 1/8 inch and plate thickness plus 1/4 inch. The instrument gain shall be adjusted to peak the first back reflection from the plate adjacent to the weld not less than once each foot along the length of the weld as specified hereafter. When a dB control is used, the instrument shall be adjusted to peak the first back reflection at not less than 20 percent of full screen. The gain shall be increased 12 dB. At this setting, the 20 percent line on the screen is the DRL, and the ARL is 10 dB above this line (see figure 24). When a dB control is not used, the viewing screen shall be divided into three zones with horizontal lines at 20 percent (the DRL) and 65 percent (the ARL) of full screen height. The instrument gain control shall be adjusted so that the peak of the first back reflection coincides with the 80 percent line (see figure 25).

6.6.4.4.1.3 Procedure. The width of the inspection zone, as determined by ultrasonic or mechanical means, shall be located and marked on the test surface. The weld shall be continuously scanned within the width of the inspection zone (see figure 23). If a discontinuity is located, the equipment gain shall be recalibrated on the through member plate adjacent to the discontinuity. The search unit shall then be positioned to maximize the discontinuity signal. To determine the length of a discontinuity, the search unit shall be moved along the axis of the discontinuity in one direction from the position of maximum signal amplitude. When the amplitude drops below the DRL, the scanning surface shall be marked at the position indicated by the center of the search unit. This shall be one extremity of the discontinuity. The process shall be repeated to determine the other extremity. The length of the discontinuity shall be the distance between these two marks. The maximum signal amplitude and length of discontinuities within the inspection zone shall be determined and reported for discontinuities yielding a signal amplitude equal to or exceeding the DRL.

6.6.4.4.2 Detection of discontinuities into the through member. This section specifies the ultrasonic inspection procedure to be used for the detection of discontinuities extending into the through member of full and partial penetration tee welds.

6.6.4.4.2.1 Inspection zone. The depth of the inspection zone shall be from the through member surface into the through member 1/4 inch inclusive. The depth of the inspection zone shall be expanded to determine the maximum depth of discontinuities extending into the through member. The width of the inspection zone shall be limited to the thickness of the attachment member plus the fillet reinforcement (see figure 26). If the particular configuration to be inspected is not discussed in this document, a method should be used which assures that complete coverage of the inspection zone will be obtained.

6.6.4.4.2.2 Search units. The diameter or length or width of the transducer shall be not greater than 1 inch. The frequency shall not be less than 2.0 MHz. The transducers used for shear wave tests shall be affixed to suitable wedges designed to induce shear waves in the material under test at a specific angle from 45 to and including 60 degrees. Supplemental beam angles may be used for the detection and evaluation of discontinuities.

6.6.4.4.2.3 Calibration. The instrument range and delay controls shall be adjusted to discriminate and indicate signals on the viewing screen from the depth of the inspection zone. When a dB control is used, the instrument gain shall be adjusted to peak the signal from the calibration hole that is not more than plus or minus 1/4 inch from the through member thickness, to not less than 20 percent of full screen height. The gain shall then be increased by 12 dB. At this setting, the line established by the original signal height on the viewing screen is the DRL and the ARL is 12 dB above this line. When a dB control is not used, the instrument gain shall be adjusted to peak the signal from the calibration hole that is not greater than plus or minus 1/4 inch from the through member thickness to not less than 80 percent of full screen. The corresponding depth and location of the peaked signals from the reference calibration standard shall be marked along the base line of the viewing screen. The screen shall be divided by two horizontal lines at 20 percent (the DRL) and 80 percent (the ARL) of full screen height.

6.6.4.4.2.4 Procedure. Shear wave scanning for discontinuities into the through member in any tee weld configuration shall be performed as shown on figure 27 whenever the surface opposite the attachment member is accessible. If the surface opposite the weld is not accessible and the side adjacent is accessible, the scanning shall be accomplished as shown on figure 26; however, there shall be no attachments in the area where the reflection of the wave occurs. Coverage in each direction, as illustrated on figure 26 and figure 27, shall be from the nearest toe of the weld to beyond the center of the weld, thus avoiding the necessity of interpreting indications from the surface of the far fillet. The shear wave search unit shall be placed on the scanning surface and directed toward the particular inspection zone. The search unit shall be oscillated to the left and right with an included angle of approximately 30 degrees in a radial motion while scanning perpendicularly toward the inspection zone. The inspection zones are specified in 6.6.4.3.4, 6.6.4.4.2.1. Continuous scanning shall be used. When any indication is noted from a discontinuity within the inspection zone, the sound beam shall be directed to maximize the indication. The maximum signal amplitude, length, depth, and position shall be determined and reported for discontinuities yielding a signal amplitude equal to, or exceeding, the DRL. The length of discontinuities shall be determined as specified in 6.6.4.4.1.3. The recorded depth of a discontinuity shall be the minimum and maximum perpendicular distances of the discontinuity from the through member surface. This should be determined in the following manner:

(a) Maximize the indication from the discontinuity.

(b) For discontinuities extending to a surface, move the search unit toward the discontinuity and record the depth from the viewing screen at which the indication begins to drop rapidly toward the base line.

(c) In addition, for discontinuities which do not extend to the surface, repeat the above and move the search unit away from the discontinuity to determine the other limit of depth at the point where the indication again begins to drop rapidly toward the base line.

6.6.4.4.3 Volumetric inspection of full penetration tee welds. Inspection shall be performed in accordance with 6.6.4.3, as modified herein. The inspection zone shall include the entire weld volume extending from the weld toes of the beveled member to the fusion line with the through member including the design fillet reinforcement and all associated heat-affected zones (HAZs). Scanning shall be as required to ensure complete coverage of the inspection zone for the detection of longitudinal discontinuities (see figure 28). When scanning from the beveled member, the inspection angle shall be based on the beveled member thickness as specified in 6.6.4.3.2. When scanning from the through member, the inspection angle shall be 45 degrees. When accessible, scanning for transverse discontinuities shall be accomplished from the opposite side of the through member with the transducer positioned over the weld zone and the beam directed along the longitudinal weld axis. Alternatively, scanning for transverse discontinuities may be accomplished from the beveled member as specified in 6.6.4.3.4.2.

6.6.4.5 Record of inspection results. The record data sheet for inspection results of welds shall contain as a minimum the following information (for suggested forms see figure 29):

(a) Ship/item identification.
(b) Location (frame, side of ship, and so forth).
(c) Type of material.
(d) Thickness of material.
(e) Joint identification.
(f) Type of weld joint (weld design).
(g) Weld length inspected.
(h) Operational procedure identification.
(i) Equipment used for inspection (instrument and search unit).
(j) Reference block identification.
(k) Discontinuities that exceed the DRL.
(l) Acceptance or rejection.
(m) Signature of inspection personnel.
(n) Date.
(o) If supplemental ultrasonic inspection techniques are used that contribute to the final inspection results, they shall be recorded.

6.7 Thickness measurements.

6.7.1 Scope. Variations in wall thickness may be measured by either pulse-echo instruments or resonant frequency instruments, which have been qualified as specified in 6.5.1.3. When using numeric-style digital readouts and the reflecting surfaces are, or are believed to be, rough, pitted, or corroded, an A-scan type display shall be used to verify the digital readings.

6.7.2 Calibration. The instrument shall be calibrated on a set of standards of the same basic material (acoustically similar) as that to be inspected. No less than two standards shall be used—one shall be equal to or less than the minimum acceptable thickness and one shall be equal to or greater than the maximum acceptable thickness (if applicable). As an alternative for materials equal to or greater than 1 inch thick, multiple back reflections from 1/2 inch, 3/4 inch, or thicker blocks may be used. If the inspection is only to determine minimum thickness violations, then one calibration standard equal to the minimum thickness is allowed. Flat standards may be used for pipe and tubing 3/4-inch nominal diameter and over.

6.7.3 Method. The number and location of ultrasonic thickness measurements taken shall be as specified in the applicable material specification, fabrication document, or work authorization document. Measurements may be made manually or by automated equipment that meets the requirements of 6.5.1.3.

6.8 Bond testing of weld deposited materials.

6.8.1 Scope. This subsection only describes the requirements for the ultrasonic inspection of the bond of weld deposited material to base material. Specific requirements due to special shapes of manufacturing processes shall be as specified in the appropriate specifications.

6.8.1.1 Method. Inspection of the bond of weld deposited material to base material shall be by the contact method. The transducer may be fitted with appropriate shoes, wedges, or saddles for testing on curved surfaces or at desired angles.

6.8.2 Transducers. Transducers shall be not greater than 1 inch square or 1-1/8 inch diameter, and shall operate within a range of 2.25 to 10.0 MHz.

6.8.3 Calibration of test equipment. Calibration of ultrasonic test equipment shall be performed on a reference calibration block to establish adequate sensitivity for testing. The calibration blocks shall meet the surface finish requirements of 6.3.2. The calibration blocks shall be prepared by weld deposited cladding, pads, or buttering onto a block of the same S-number (or equivalent as defined in MIL-STD-278, para 10.4.4.1) base material as the production part. The weld deposited metal used must be of the same A-number as that on the production part to be examined and may be deposited by any approved welding process. In addition, the following requirements in (a) through (g) shall be met (the S-numbers and A-numbers for base metal and weld metal are defined in MIL-STD-278):

(a) The microinch surface finish of the calibration block shall be equal to or greater than the production part to be inspected.

(b) The calibration block base material shall be equal in thickness to the production part base material except that, for thicknesses exceeding 1 inch, the calibration block base material may be 1 inch or greater. For welding large flat, or essentially flat surfaces, a 6-inch square shall be the minimum acceptable calibration block.

(c) The weld metal thickness of the calibration block shall be within plus or minus 25 percent of that on the production part.

(d) The transducer contact area of the production part shall be equal to or greater than the transducer contact area on the calibration block.

(e) For convex production surfaces, the calibration block shall be convex with a radius of curvature equal to or less than the production surface to be examined.

(f) For concave production surfaces, the calibration block may be flat or concave with a radius of curvature equal to or greater than the production surface to be examined.

(g) An area of the block approximately 2 inches square shall have the backing material removed, leaving only the cladding. An ultrasonic thickness measurement at 2.25 MHz shall be established in this area, representing unbond. The thickness pattern obtained in the area of integral cladding and base material shall represent good bond and the first clearly visible reflection from the opposite side of the block shall be not greater than full screen amplitude. Calibration shall be obtained with the search unit moving across the surface at approximately the same speed as that to be used during the inspection.

6.8.4 Scanning. Scanning shall be performed manually or automatically by moving the search unit in a directed path or by moving the material in a directed path with the search unit stationary. Scanning shall be performed at a uniform rate of speed determined during calibration, so that any indication relative to the quality of the material shall be detected.

6.8.4.1 Continuous scanning. Unless otherwise specified in the appropriate specifications, the continuous scanning procedure shall be followed. All testing shall be performed with the search unit in contact with the clad surface. Sound transmission into the base material shall be confirmed by observing the composite thickness pattern as obtained from the good bond area of the calibration block. When the back reflection is lost due to nonparallel surfaces of the base materials, transmission shall be confirmed by the test specified in 6.8.4.3.

6.8.4.2 Intermittent scanning. Scanning shall be performed along special paths or on grid lines. The distance between paths or lines shall be as specified in the appropriate specification when the method is required.

6.8.4.3 Calibration for ultrasonic testing of nonparallel surfaces. Test equipment shall be calibrated with the same calibration block as specified in 6.8.3. The thickness pattern shall be observed by scanning over the clad surface where the backing material has been removed, and the equipment shall be set to demonstrate a full screen back reflection. Using these settings, the operator shall scan over the composite thickness of the cladding and the backing material and note the normal back reflection from the good bond.

6.8.4.4 Continuous scanning of nonparallel surfaces. Unless otherwise specified in the applicable specifications, each pass across the test surface shall overlap 25 percent of the previous pass until the entire surface has been scanned. The equipment settings established in 6.8.4.3 calibration shall be used.

6.8.5 Marking. When an indication in excess of acceptance standards occurs, the material shall be appropriately marked.

6.8.6 Flaw plotting. Each defect shall be explored ultrasonically to determine its size. The edge of the defect shall be determined by moving the search unit toward the defect and noting the position of the leading edge of the transducer when the defect first appears. The length of the defect shall be determined by continuing to move the search unit across the defective area and noting the trailing edge of the transducer when the indication disappears. The distance between defects shall be determined by measuring the shortest distance between their edges regardless of indication amplitude at these points.

7. EDDY CURRENT TESTING.

7.1 Intended use. The inspection process covered is for the detection of surface cracks of ferromagnetic and nonferromagnetic materials. This method may only be used when authorized by the fabrication document, military specification, or other NAVSEA approval.

7.2 Definitions. The standard terminology for electromagnetic testing as described in ASTM E 1316 shall apply to this section.

7.3 Eddy current inspection requirements.

7.3.1 General requirements.

7.3.1.1 Method. The overall inspection process shall consist of applying the eddy current test (ET) technique to detect surface cracks in the item inspected.

7.3.1.2 Surface finish. The surface for the eddy current test scanning does not require paint removal, but it shall be reasonably smooth and clean. It shall be free of any substance that might inhibit free movement of the probe along the scan path.

7.3.2 Procedure. Eddy current inspection procedures shall contain, as a minimum, the following information.

(a) Material to be tested.
(b) Summary of process used.
(c) Equipment description.
(d) Performance verification description.
(e) Surface preparation.
(f) Calibration/normalization technique.
(g) Scanning technique.
(h) Evaluation technique.
(i) Evaluation criteria.
(j) Recording and reporting requirements.

7.3.3 Records. Records of eddy current inspection shall contain the following:

(a) Description and unique identification of item inspected.
(b) Approved procedure identification.
(c) Instrument manufacturer and model number.
(d) Probe description.
(e) Material type.
(f) Acceptance standard used.
(g) Date of inspection.
(h) Signatures of inspectors.
(i) Disposition of the item inspected.

7.4 Equipment requirements.

7.4.1 Eddy current instrument. The instrumentation shall be capable of signal evaluation by both visual (meter readout) and audio sound pitch variations through connecting headphones, or by an impedance plane storage-type display. For weld inspections, an impedance plane storage-type display instrument shall be used. The instrument shall provide a means for minimizing or adequately separating the effect of the lift off variable in the evaluation of test results. It shall be capable of detecting the notch in the performance verification block being used.

7.4.2 Performance verification reference block. A block of the same material type that is to be inspected shall be used. If the material to be inspected is coated or painted, the verification block shall have the same type and maximum possible thickness of coating which will be encountered in the actual inspection. The block may be any convenient size provided that it does not present an edge-effect problem. The block shall contain a notch that is 0.015 inch deep by 0.250 inch long with a width of 0.010 inch (maximum dimensions). Blocks used for the inspection of welds shall be welded and shall represent the same general surface condition (such as welded, ground flush) and configuration (such as tee, butt) as the weld being inspected with both a longitudinally and transversely oriented notch.

7.5 Calibration. Prior to performing an inspection, verify the instrument performance using the appropriate performance verification block. This test shall produce a useable response from the notch(es) and shall be discernable from any material surface noise signal. The eddy current instrumentation shall then be normalized on an experimentally determined defect-free area representative of the item to be inspected. Calibration shall be accomplished at the following times:

(a) Immediately prior to starting an inspection.

(b) Whenever an inspection has been interrupted by the equipment being turned off or left unattended by the inspector.

(c) Whenever the inspector has reason to suspect that conditions affecting the calibration have changed.

(d) When in use, not less than every 4 hours.

7.6 Test technique.

7.6.1 Toe of weld scan. With the probe oriented to scan parallel to the weld longitudinal axis, scan along each toe of the weld. Ensure that the probe is maintained at a constant attitude to the toe of the weld, keeping the working edge of the probe in full contact. Monitor the weld condition by noting the response in the instrument display. Avoid rocking the probe or tilting it in a position other than as used during calibration (see figure 30 for optimum positioning). For the toe of weld scan, either visual display (meter readout) with audio pitch variation through headphone equipment, or impedance plane storage-type display equipment may be used.

7.6.2 Weld scan. With the probe oriented to scan parallel to one weld toe, scan the weld for the desired distance. Repeat this scanning process such that the entire weld and heat affected zone is covered. The weld shall also be scanned in the transverse direction, unless the probe has been verified to be able to detect both longitudinal and transverse indications with one scan.

7.6.3 Inspection of surfaces other than welds. With the probe oriented at a consistent attitude to the work piece, keep the working face of the probe in full contact with the work piece at all times during scanning. To ensure detection of linear indications having axes in any direction, not less than two separate scans shall be made in each area, the second scan shall be at right angles to that used in the first, unless the probe has been verified to be able to detect both longitudinal and transverse indications with one scan.

7.6.4 Indexing. Except as allowed below, each scan of the probe shall be indexed not greater than 1/8 inch from the previous scan. Indexing greater than 1/8 inch may be used when approved by the Government Inspector, provided adequate defect detection for a particular type of equipment and geometry has been demonstrated.

7.7 Evaluation of test results. Evaluate the surface conditions by monitoring the signal response produced. Any portions of the item that produce flaw signal response equal or greater than the flaw signal response from the performance verification block shall be inspected by magnetic particle inspection (for ferrous materials) or liquid penetrant inspection for (non-ferrous materials). The accept/reject criteria for the magnetic particle/liquid penetrant inspection shall be as established by paragraph 1.3. Avoid rocking or tilting the probe in any position other than that used during calibration. See figure 30 for optimum positioning.

8. VISUAL INSPECTION

8.1 Intended use. The visual inspection proces is to determine that all welds and adjacent base materials be inspected as required to comply with applicable procedures, drawings, and fabrication documents. For base material, this section shall apply only if specifically invoked by the base material specification. Drawings specifying visual testing shall employ nondestructive test symbols in accordance with AWS A2.4.

8.2 Reference standard. Visual inspection reference standards, as referred to in this section, refer to those devices that are used as an aid to visual inspection such as workmanship samples and sketches or photographs of welds or surfaces. Each activity shall be responsible for preparation of the reference standards specified in that activity's visual inspection procedure.

8.3 Procedure requirements. The visual inspection procedure shall contain, as a minimum, the following information:

(a) Type of welds or surfaces to be inspected.
(b) Measuring devices.
(c) Visual aids, or reference or working standards.
(d) List of inspection attributes (visual characteristics).
(e) Lighting requirements.
(f) Acceptance criteria and classification of defects.
(g) Record requirements.

8.4 Records. Records of visual inspection shall contain the following:

(a) Description and unique identification of item inspected.
(b) Approved procedure identification.
(c) Acceptance standard used.
(d) Date of inspection.
(e) Signatures of inspectors.
(f) Disposition (accept/reject) of the item inspected.

8.5 Inspection techniques. Visual inspection need not be performed employing magnification, unless otherwise specified in the applicable fabrication document. When a reference standard is required and magnification, such as a borescope or magnifying glass is employed, evaluation and acceptance shall be based upon comparison with a reference standard where both magnified and unmagnified appearance can be determined.

8.6 Dimensional inspection accuracy. Each activity shall ensure that the dimensional inspection techniques, including measuring devices, visual aids, and reference or working standards, are capable of measuring the specified dimensions of the items under inspection, with the required precision.

8.7 Lighting. The inspection area shall be adequately illuminated for proper evaluation.

9. NOTES

9.1 Intended use. This document covers nondestructive testing method requirements for radiographic, magnetic particle, liquid penetrant, ultrasonic, eddy current and visual inspections. These requirements are designed to ensure the integrity and reliability of inspections performed. This document does not contain acceptance criteria for the inspection methods defined.

9.2 Supersedure information. The following is a comparison of the liquid penetrant classification used in 5.3.1 of this specification to that used in 5.3.1 of MIL-STD-271F.

Designation in MIL-STD-271F	Designation in this version
Group I	Type II, Method C, Form d
Group II	Type II, Method B or D, Form a, b, c, or d
Group III	Type II, Method A, Form a, b, c, or d
Group IV	Type I, Level (any), Method A, Form a, b, c, or d
Group V	Type I, Level 2, Method B or D, Form a, b, c, or d
Group VI	Type I, Level 4, Method B or D, Form a, b, c, or d
Group VII	Type I, Levels 3 and 4, Method C, Form d

9.3 Issue of DODISS. When this document is used in acquisition, the applicable issue of the DODISS must be cited in the solicitation (see 2.1.1, and 2.2)

9.4 Subject term (key word) listing.

Circular magnetization
Compressional wave
Continuous scanning
Eddy current testing
Intermittent scanning
Liquid penetrant testing
Longitudinal magnetization
Longitudinal wave
Magnetic particle testing
Material thickness
Multiple film technique
Penetrameter
Radiographic inspection
Radiographic shooting sketch
Radioisotope radiography
Shear wave
Specimen thickness
Ultrasonic testing
Visual inspection
X-ray radiography
Yoke magnetization

9.5 Changes from previous issue. Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Preparing activity:
Navy - SH
(Project NDTI-N077)

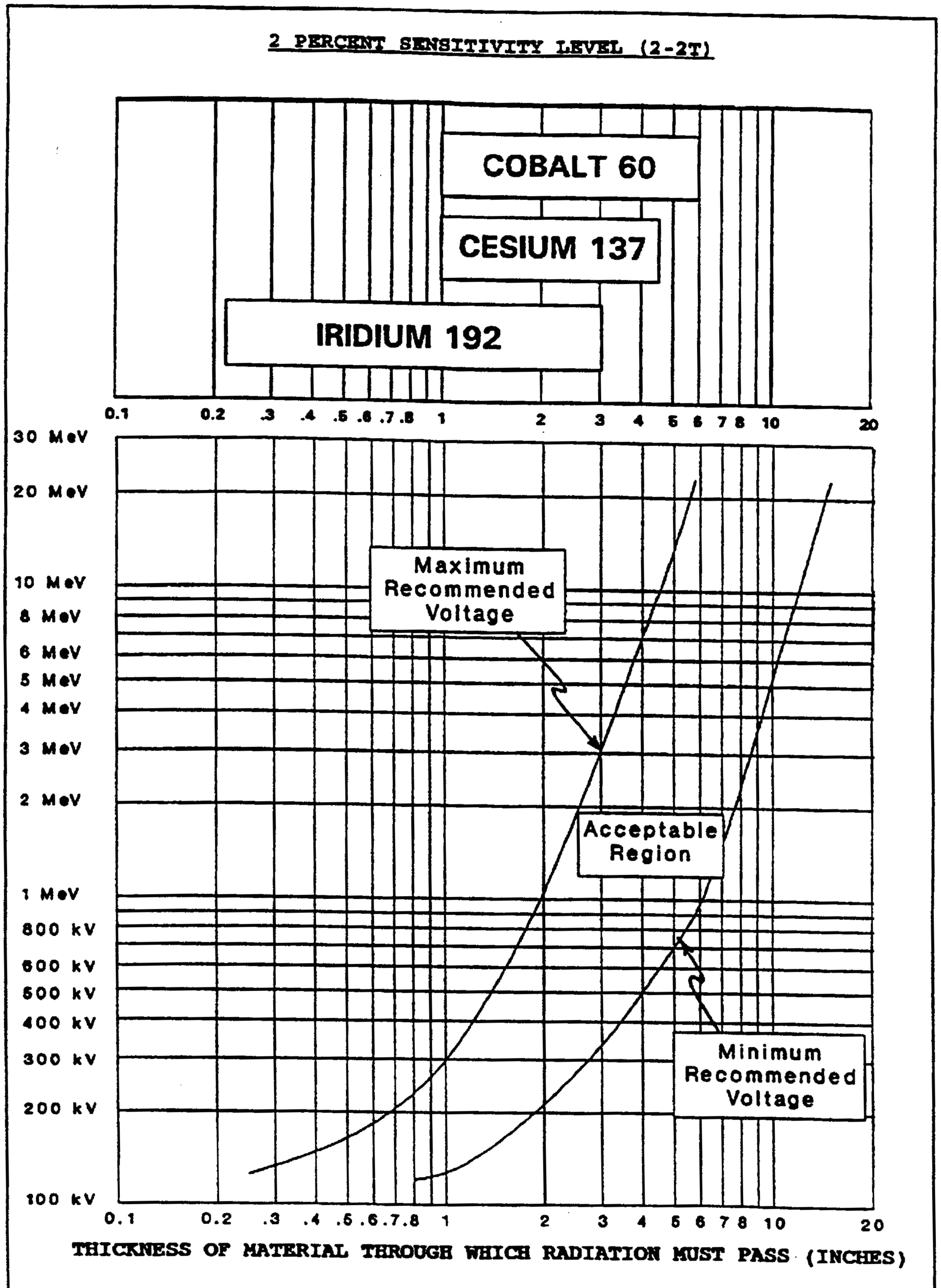


FIGURE 1. Recommended X-ray voltage settings and radioisotope sources to be used with various steel and similar alloys.

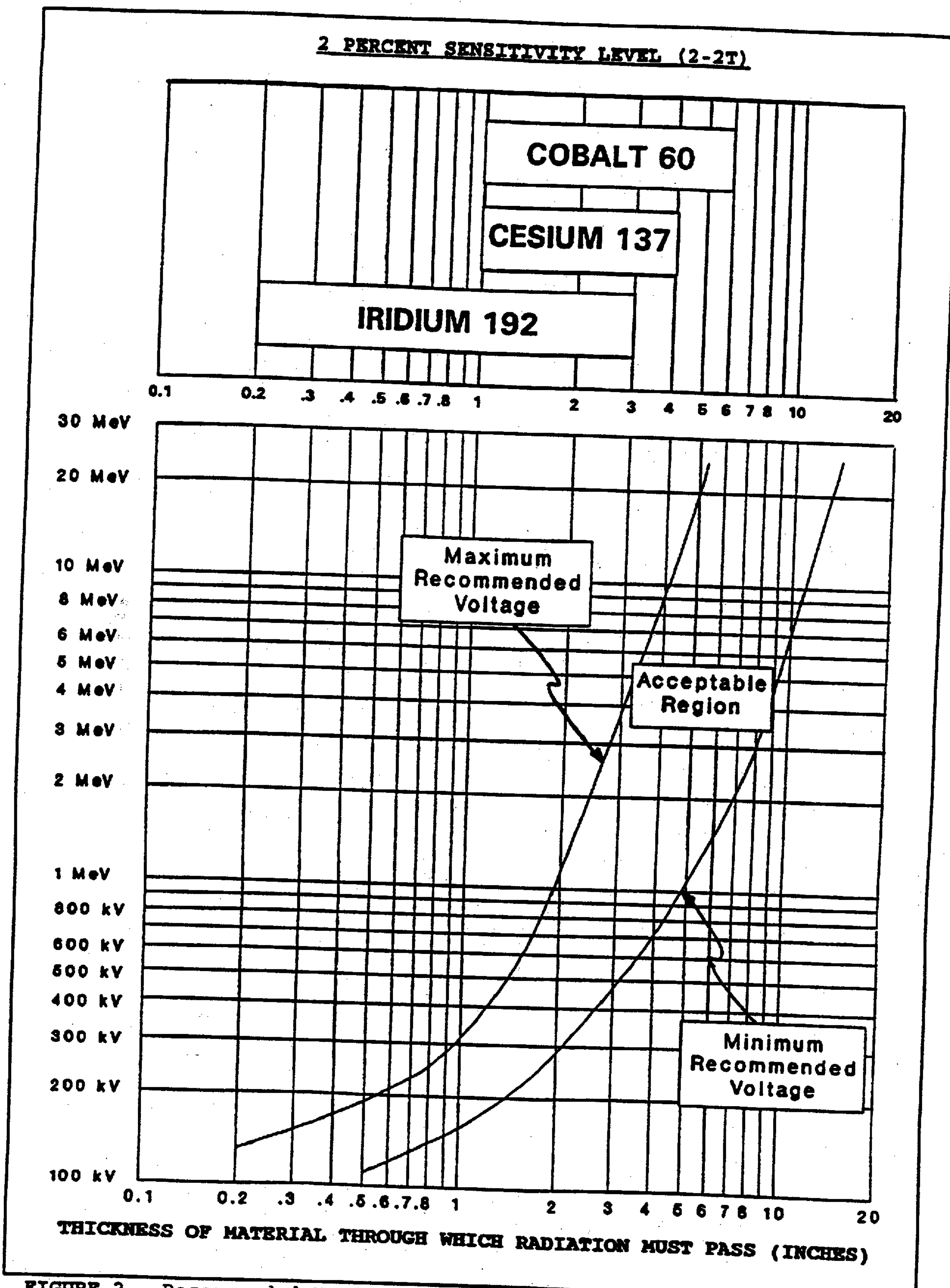


FIGURE 2. Recommended X-ray voltage settings and radioisotope sources to be used with various copper-base and similar alloys.

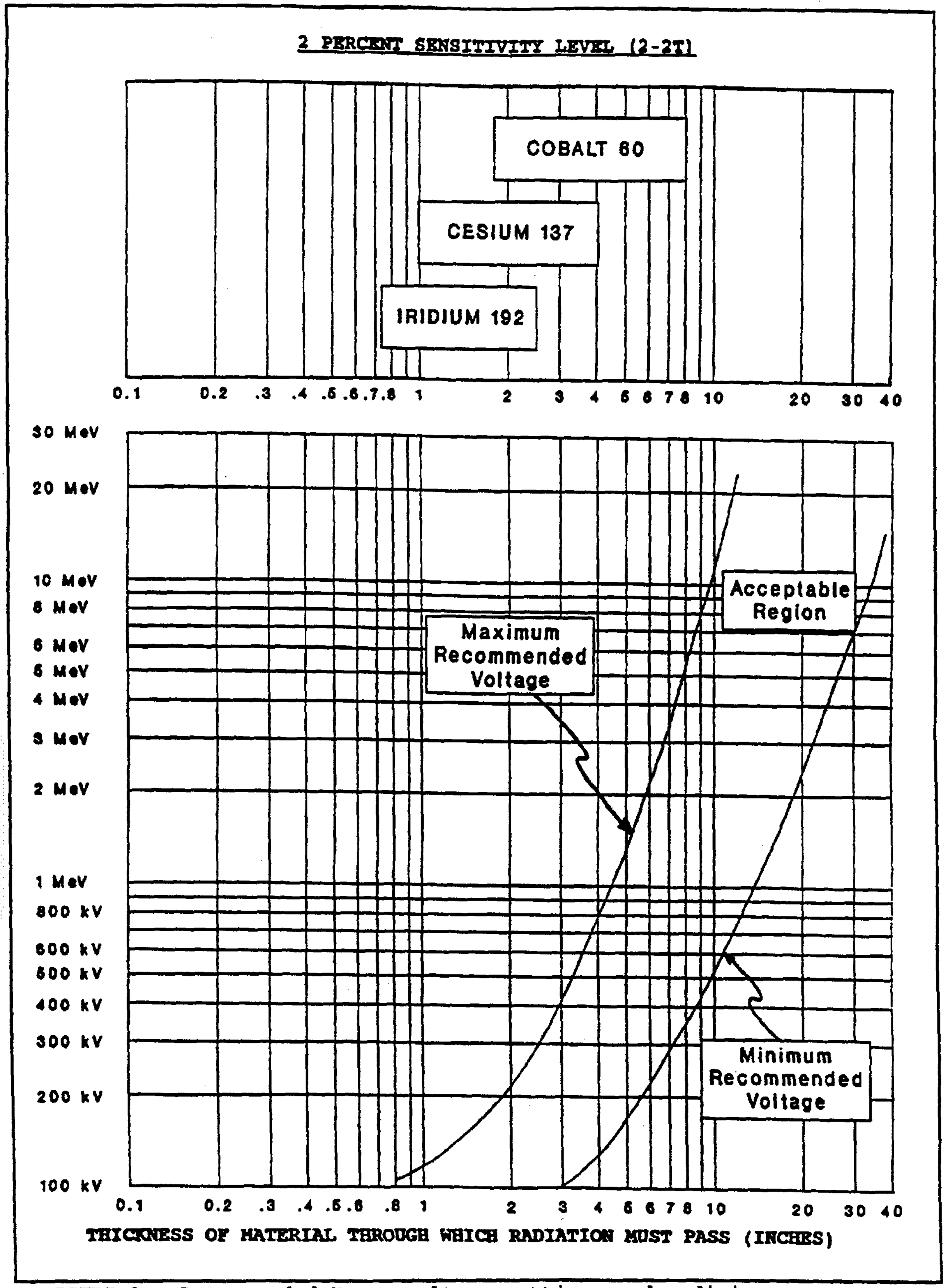
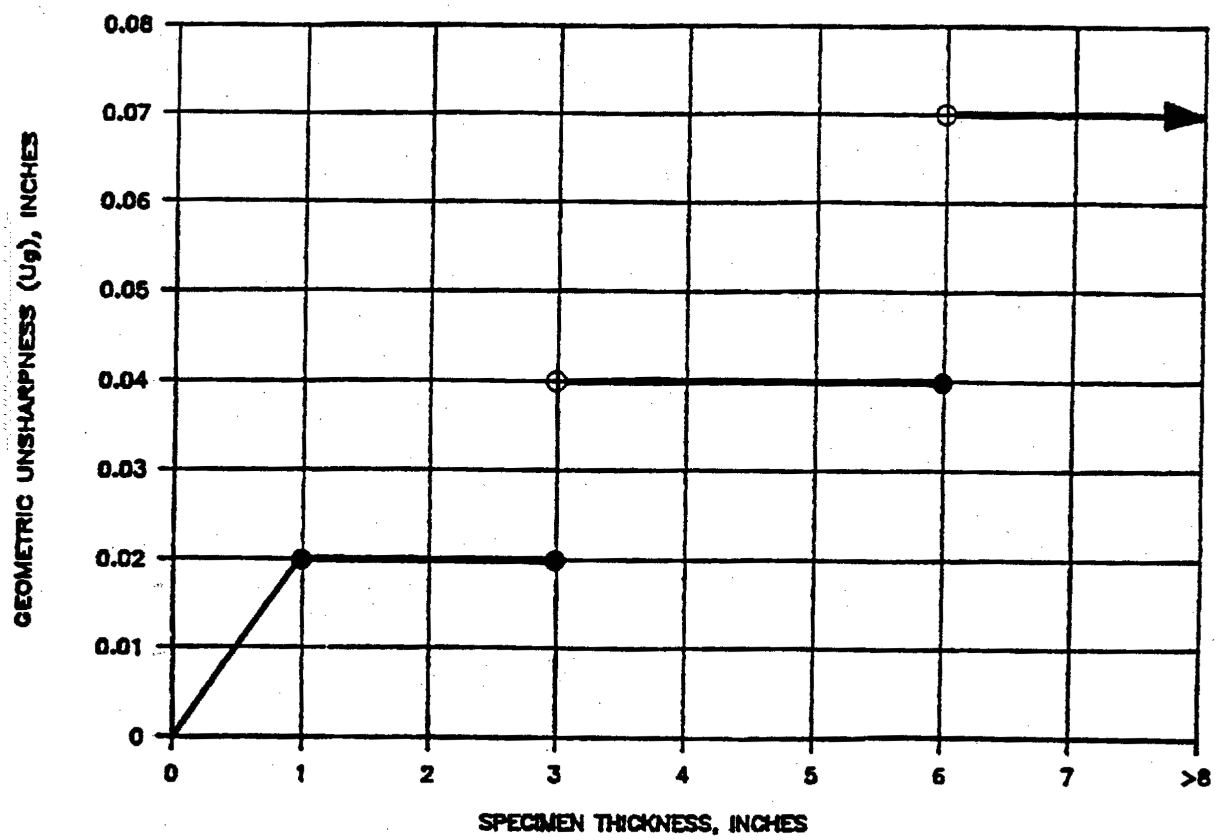


FIGURE 3. Recommended X-ray voltage settings and radioisotope sources to be used with various aluminum, magnesium and similar alloys.



Notes

1. The symbol ● indicates inclusive.
2. For specimen thicknesses less than one inch, U_g is calculated by:

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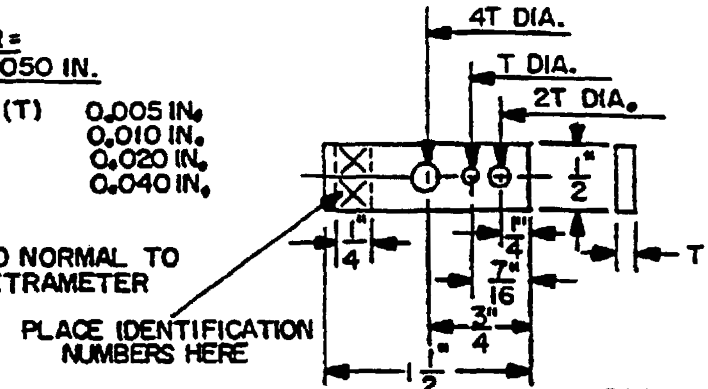
$$U_g = 0.02 \times \text{SPECIMEN THICKNESS}$$

FIGURE 4. Maximum allowed Ug.

A THICKNESS OF PENETRAMETER = 0.005 IN. TO AND INCLUDING 0.050 IN.

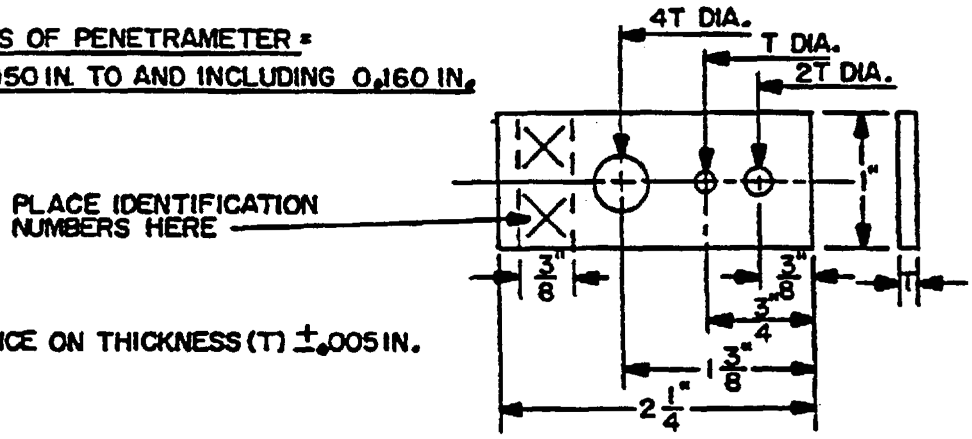
MIN PENETRAMETER THICKNESS (T)	0.005 IN.
MIN DIA FOR 1T HOLE	0.010 IN.
MIN DIA FOR 2T HOLE	0.020 IN.
MIN DIA FOR 4T HOLE	0.040 IN.

HOLES SHALL BE TRUE AND NORMAL TO THE SURFACE OF THE PENETRAMETER
DO NOT CHAMFER



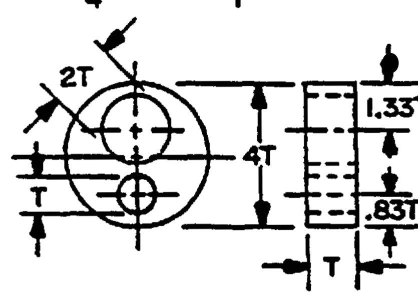
FROM 0.005 IN TO 0.020 IN → TOLERANCE ON (T) +.0001 −.001 IN.
FROM 0.020 IN TO 0.050 IN. → TOLERANCE ON (T) ±.0025 IN.

B THICKNESS OF PENETRAMETER = OVER 0.050 IN. TO AND INCLUDING 0.160 IN.



TOLERANCE ON THICKNESS (T) ±.005 IN.

C THICKNESS OF PENETRAMETER = OVER 0.160 IN.



TOLERANCE ON THICKNESS (T) ±.010 IN.

DIMENSIONAL TOLERANCES

LENGTH AND WIDTH OR DIAMETER	±1/64 IN.
HOLE DIAMETER	±10 PERCENT
HOLE LOCATION	±1/64 IN.

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FIGURE 5. Penetrameter designs.

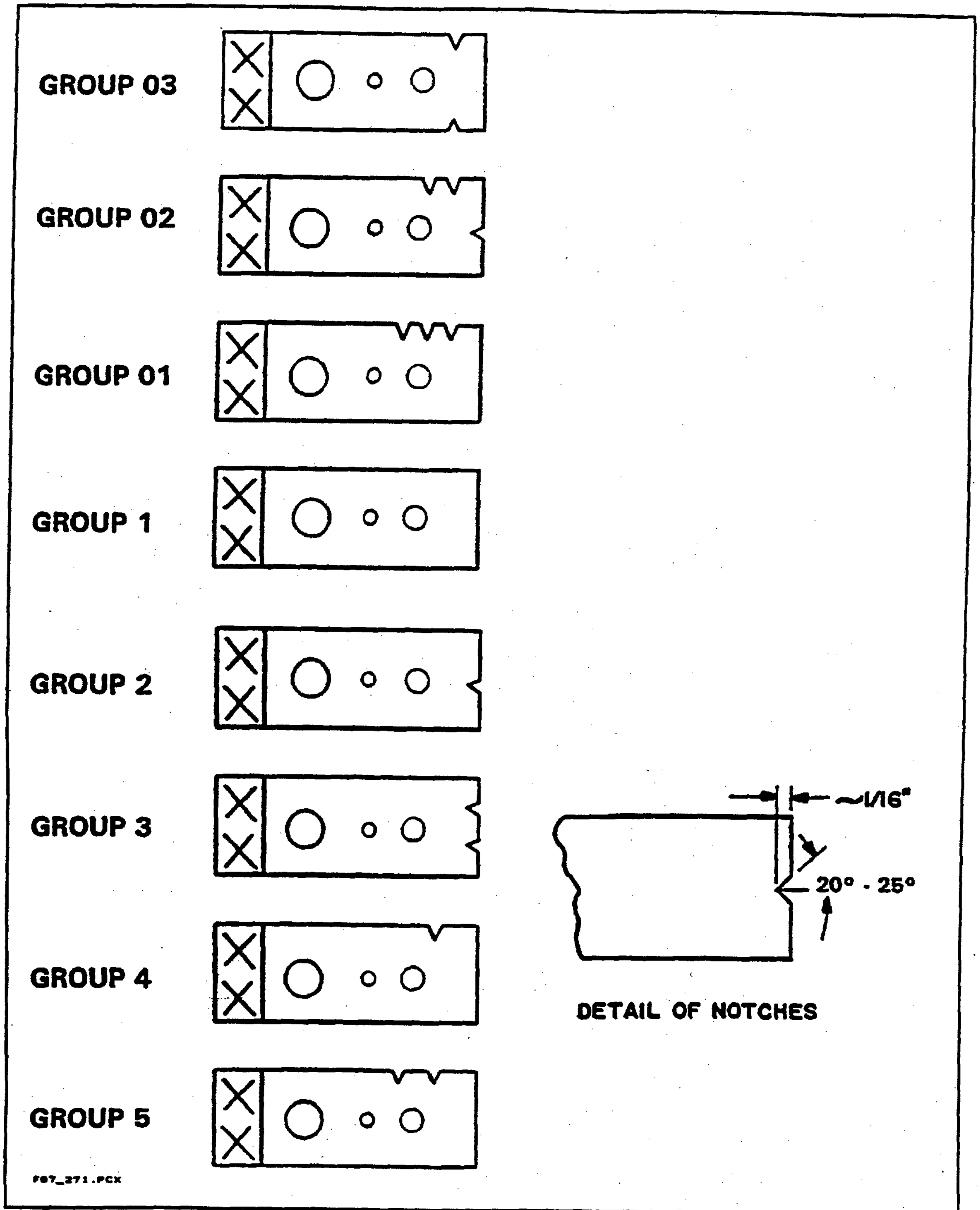
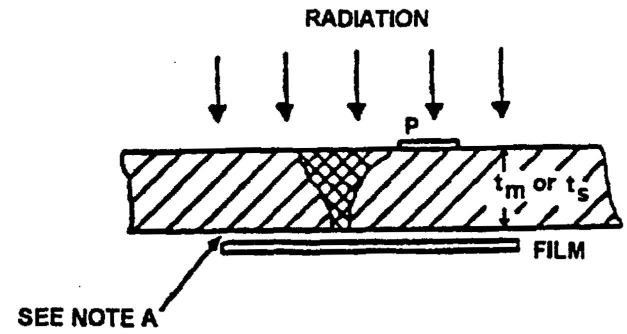


FIGURE 6. Penetrameter identification notching.



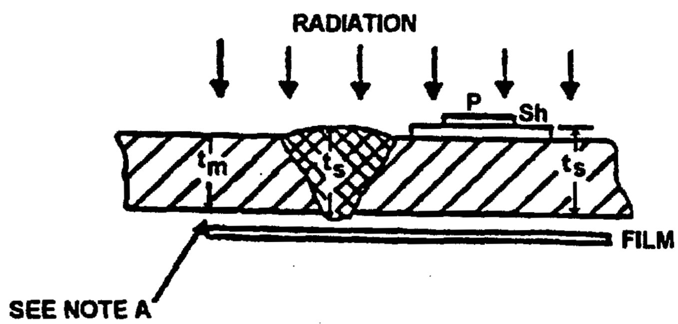
SYMBOLS

P = PENETRAMETER
Sh = SHIM
t_m = MATERIAL THICKNESS UPON WHICH THE PENETRAMETER IS BASED.
t_s = SPECIMEN THICKNESS

NOTE A:
THE FILM SHALL BE LOCATED AS CLOSE AS POSSIBLE TO THE OBJECT BEING RADIOGRAPHED.

F08_271.PCX

FIGURE 7. Examples of Tm, Ts, and penetrameter placement: single wall, no reinforcement, no back-up strip.



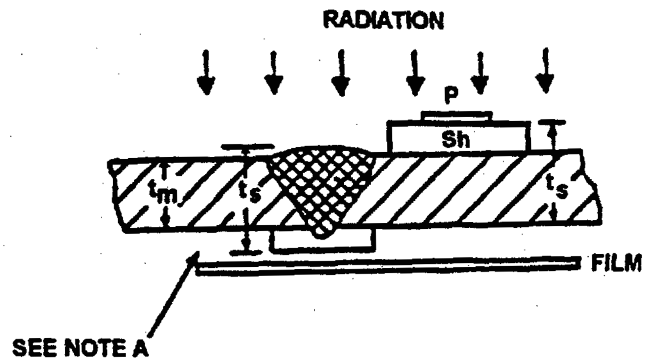
SYMBOLS

P = PENETRAMETER
Sh = SHIM
t_m = MATERIAL THICKNESS UPON WHICH THE PENETRAMETER IS BASED.
t_s = SPECIMEN THICKNESS

NOTE A:
THE FILM SHALL BE LOCATED AS CLOSE AS POSSIBLE TO THE OBJECT BEING RADIOGRAPHED.

F09_271.PCX

FIGURE 8. Examples of Tm, Ts, and penetrameter placement: single wall, weld reinforcement, no back-up strip.



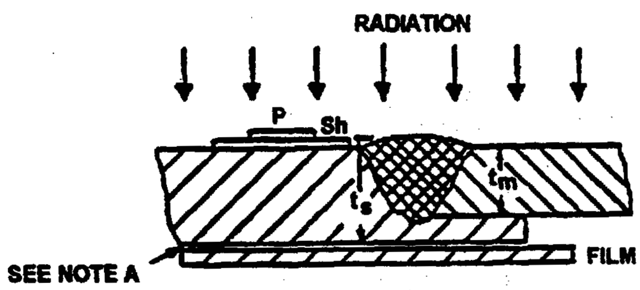
SYMBOLS

P = PENETRAMETER
Sh = SHIM
t_m = MATERIAL THICKNESS UPON WHICH THE PENETRAMETER IS BASED.
t_s = SPECIMEN THICKNESS

NOTE A:
THE FILM SHALL BE LOCATED AS CLOSE AS POSSIBLE TO THE OBJECT BEING RADIOGRAPHED.

F10_271.PCX

FIGURE 9. Examples of Tm, Ts, and penetrameter placement: single wall, weld reinforcement, back-up strip.



SYMBOLS

P = PENETRAMETER
Sh = SHIM
t_m = MATERIAL THICKNESS UPON WHICH THE PENETRAMETER IS BASED.
t_s = SPECIMEN THICKNESS

NOTE A:
THE FILM SHALL BE LOCATED AS CLOSE AS POSSIBLE TO THE OBJECT BEING RADIOGRAPHED.

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FIGURE 10. Examples of Tm, Ts, and penetrameter placement: single wall, integral backing ring, weld reinforcement.

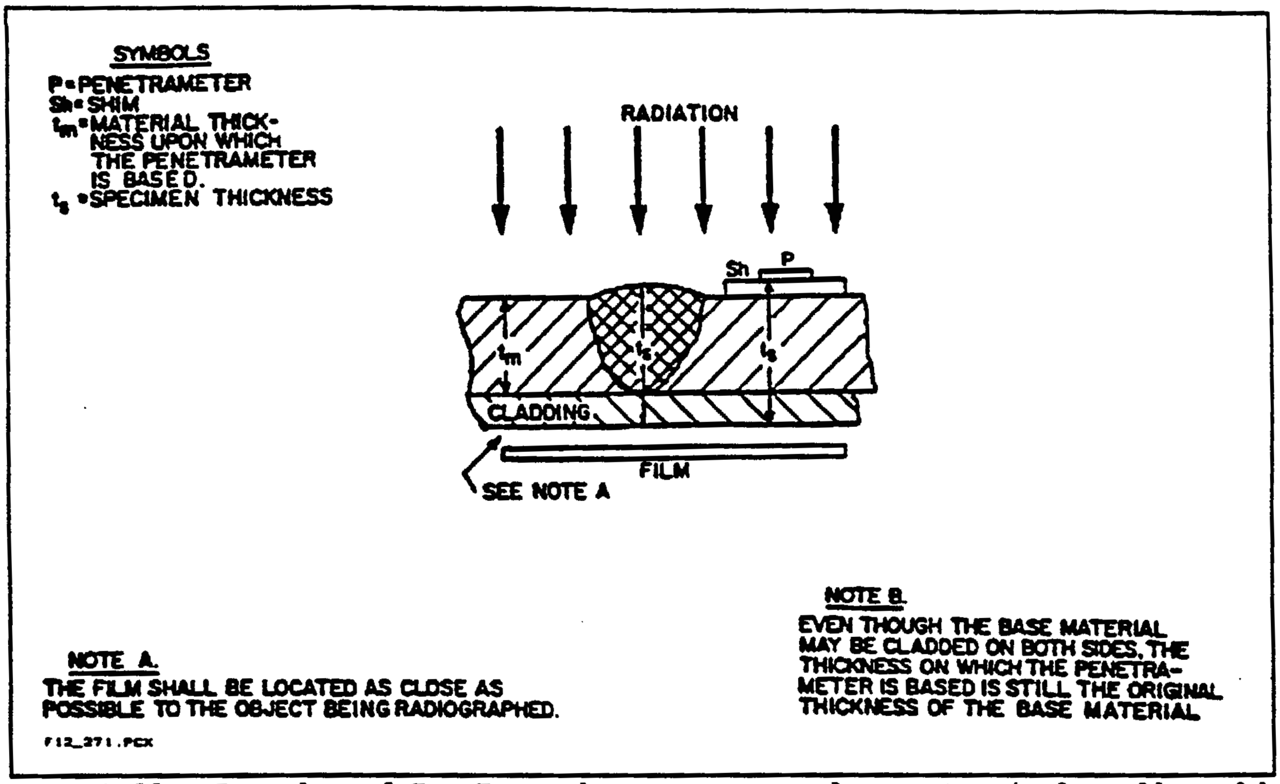


FIGURE 11. Examples of Tm, Ts, and penetrameter placement: single wall, weld reinforcement, cladding redeposited over weld in base metal.

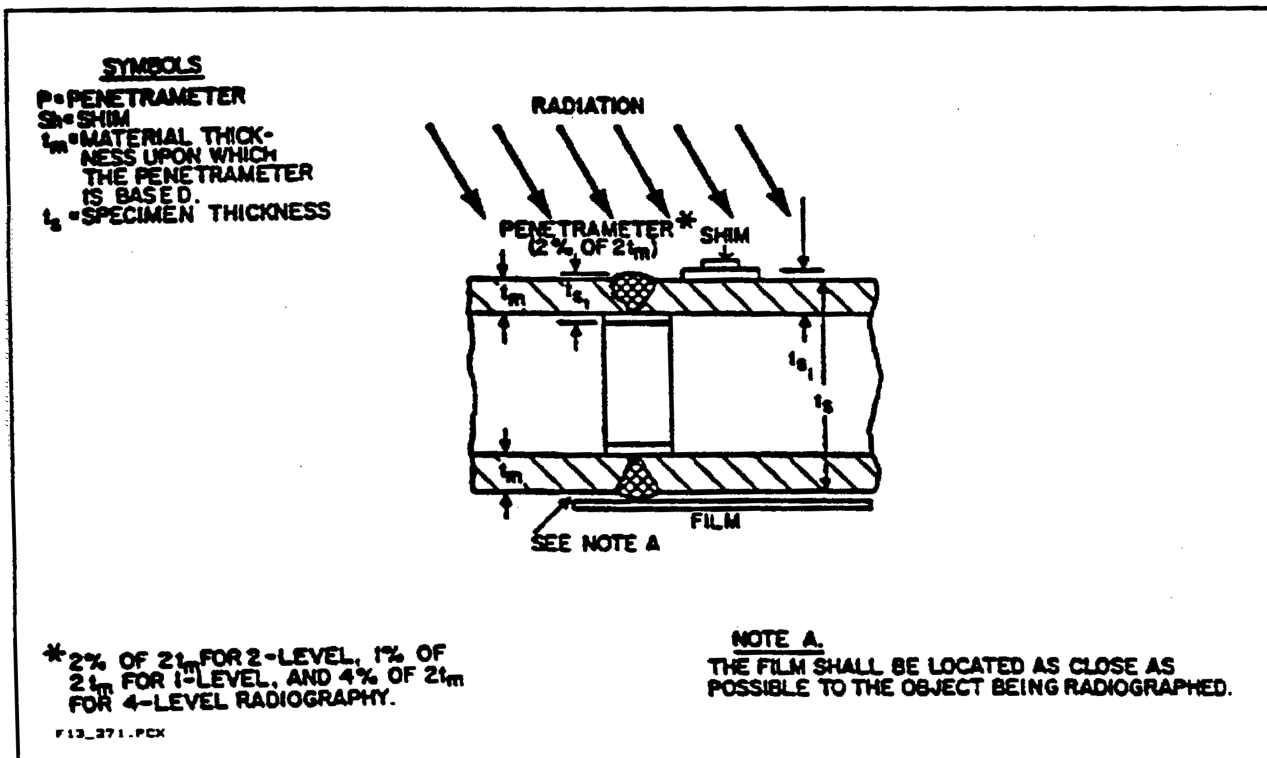


FIGURE 12. Examples of Tm, Ts, and penetrameter placement: double wall, double wall viewing, weld reinforcement and back-up strip.

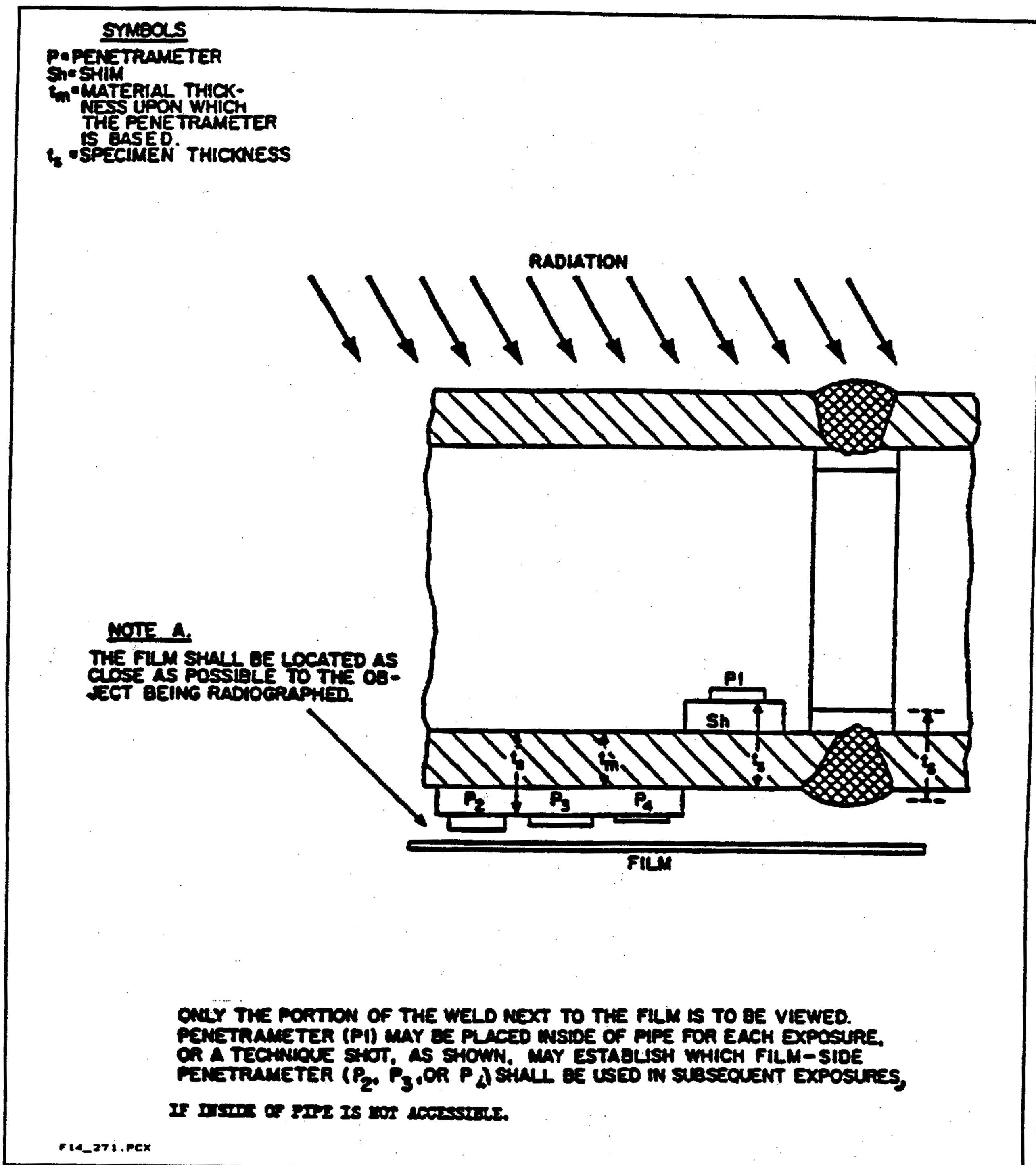


FIGURE 13. Examples of Tm, Ts, and penetrameter placement: double wall, single wall viewing.

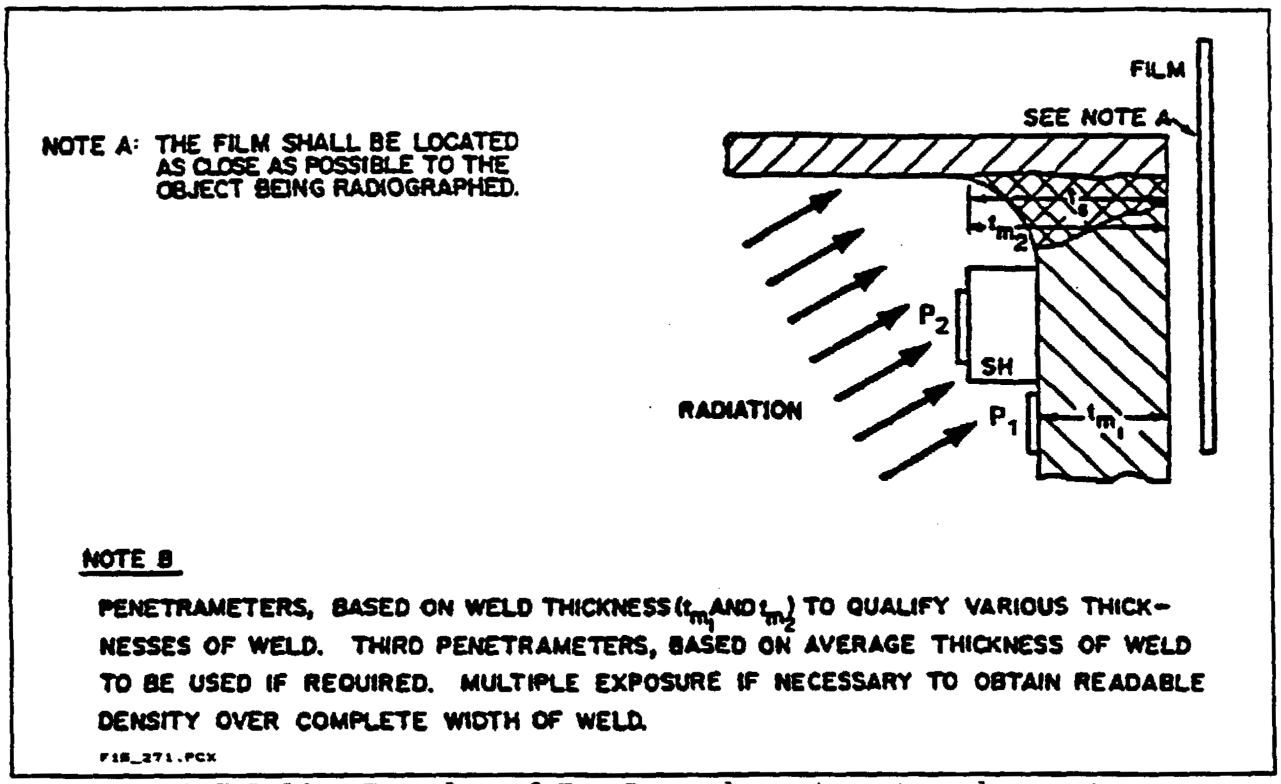


FIGURE 14. Examples of Tm, Ts, and penetrameter placement: full penetration weld, single wall.

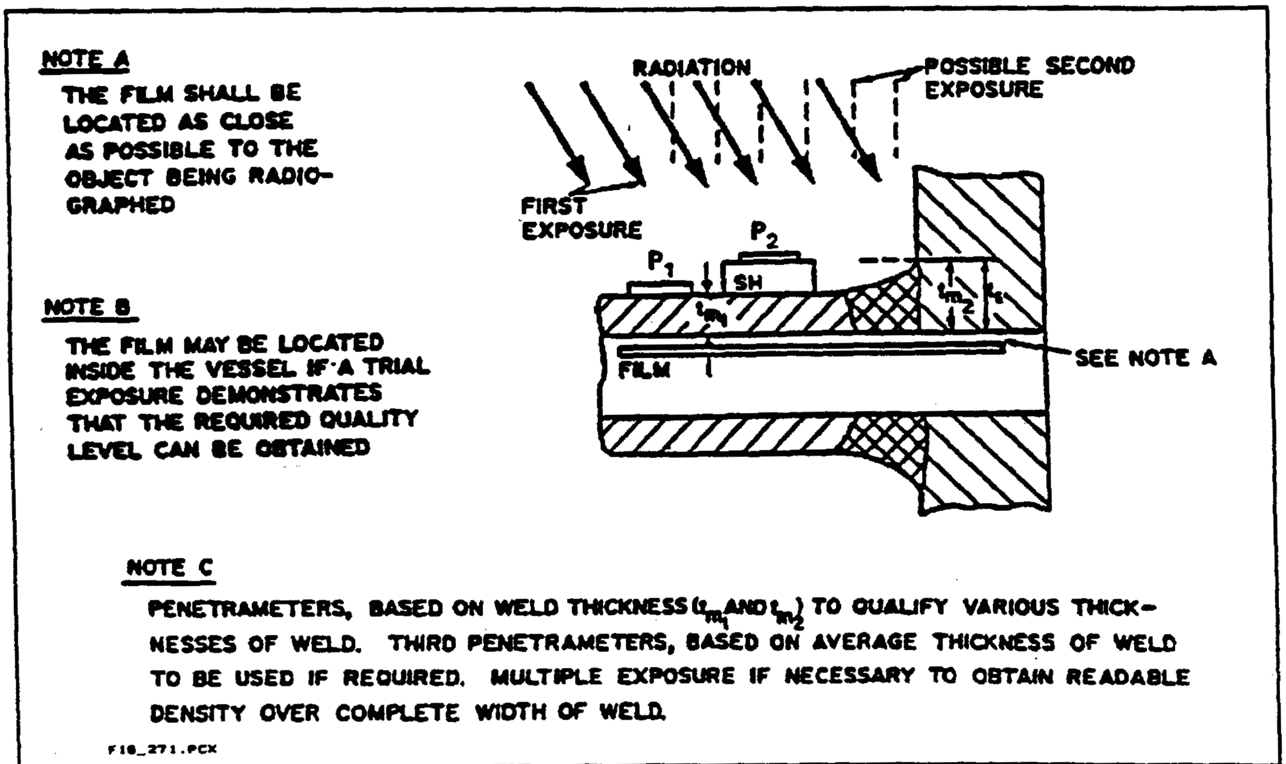
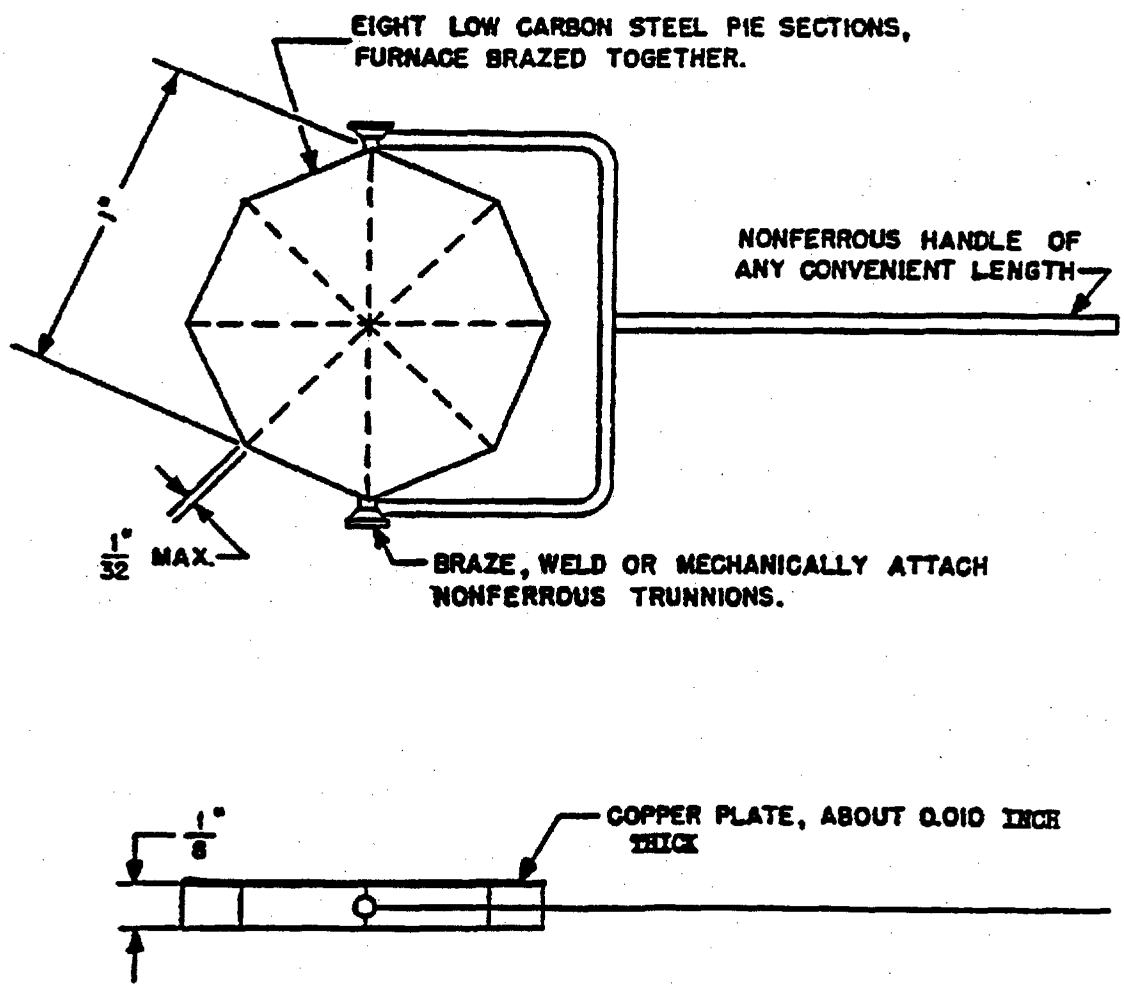


FIGURE 15. Examples of Tm, Ts, and penetrameter placement: root connection weld, single wall.



Suitable magnetic flux is indicated when the indicator is laid, copper side up, on the work piece in the area of interest and after application of the magnetic particles (and removal of excess particles for the dry powder method), and the lines at 45 and 90 degrees to the applied field are clearly visible.

F17_271.PCX

FIGURE 16. Magnetic particle field indicator.

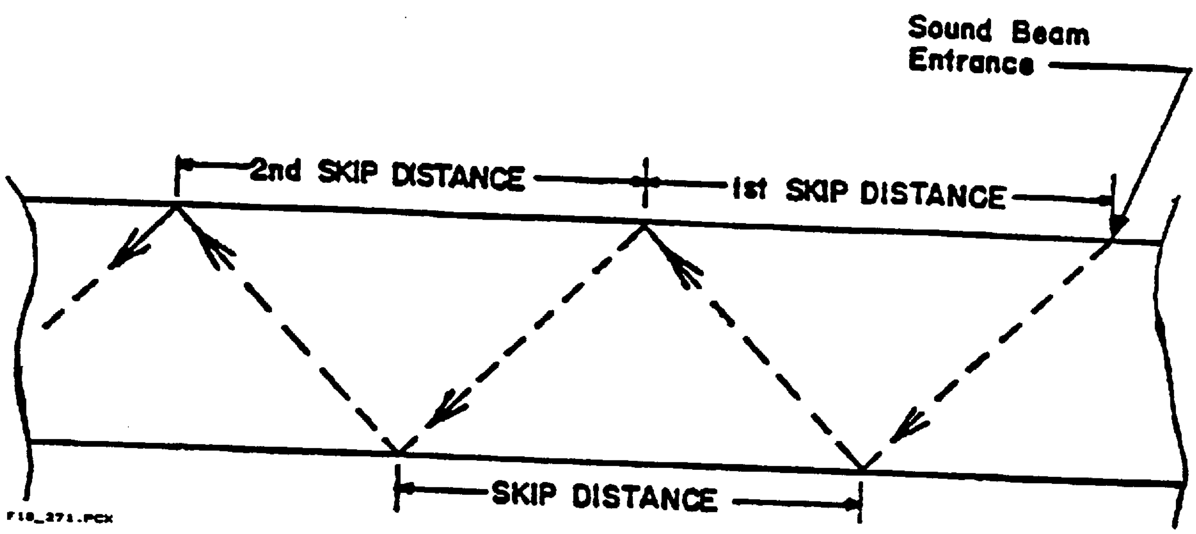


FIGURE 17. Skip distance example.

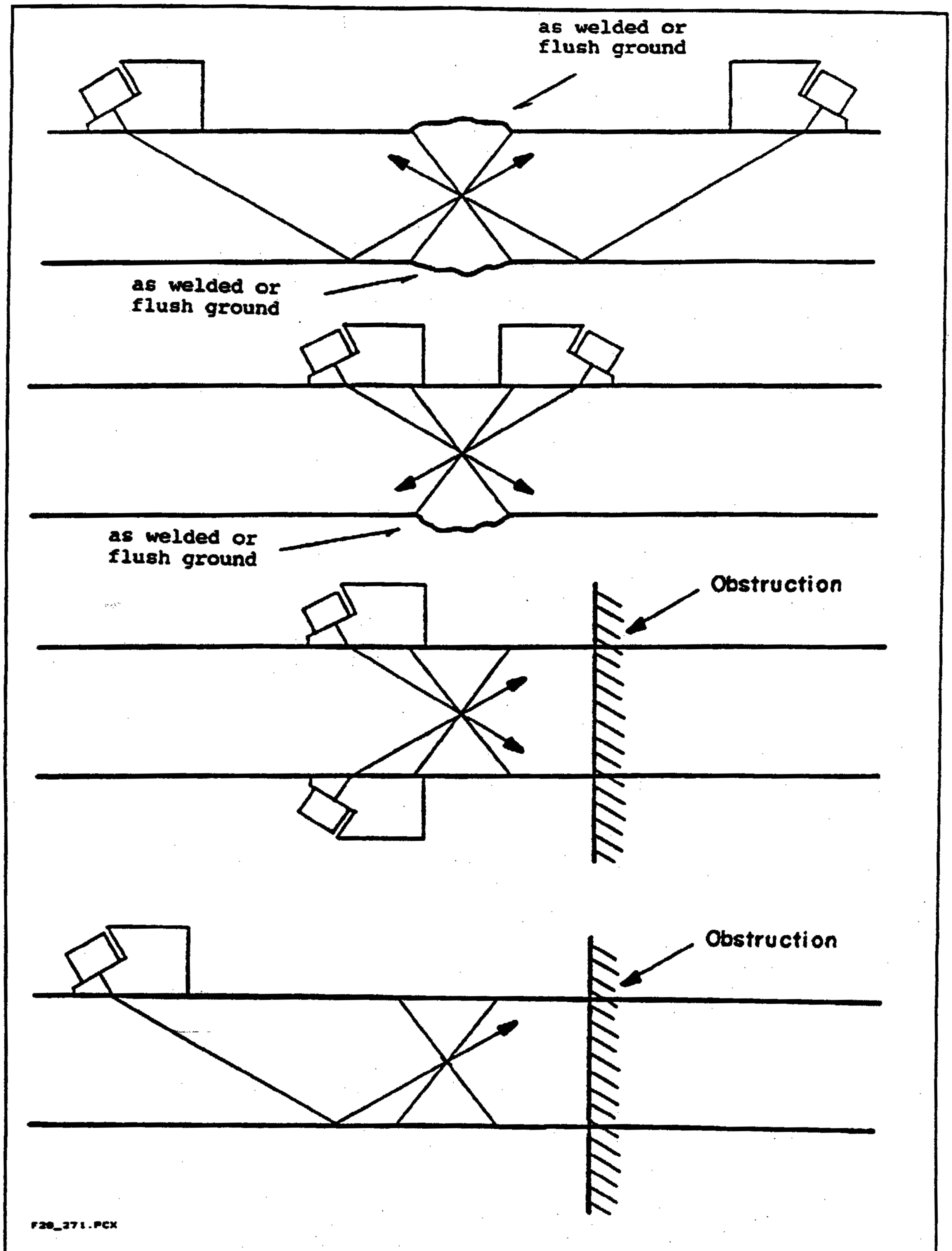
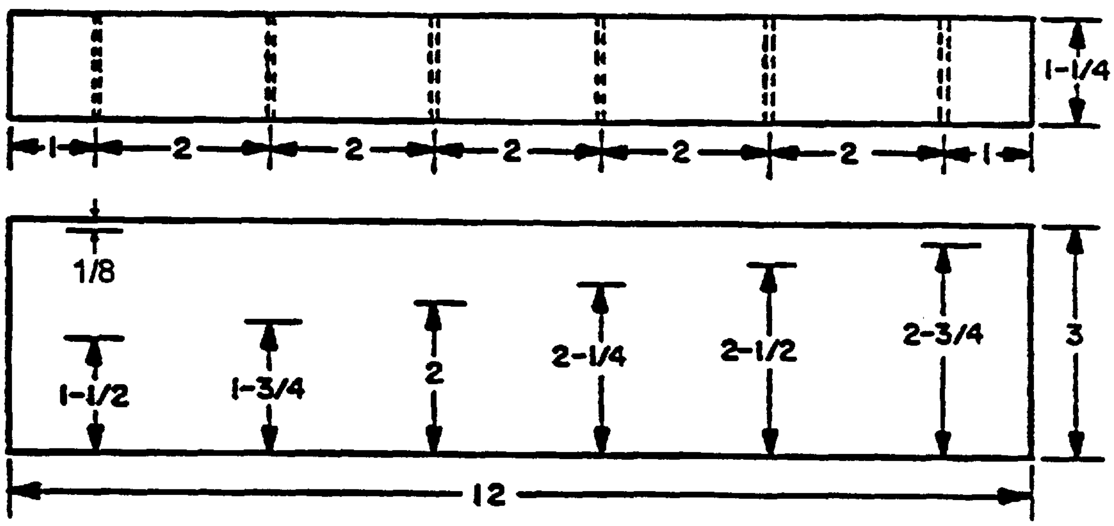


FIGURE 18. Accepted scanning techniques for butt welds.

Surface finish to be approximately 125ra as compared to surface finish standards.

Six through holes, 3/64 inch diameter.



All dimensions in inches.

F21_271.PCX

FIGURE 19. Typical reference calibration standard (sensitivity).

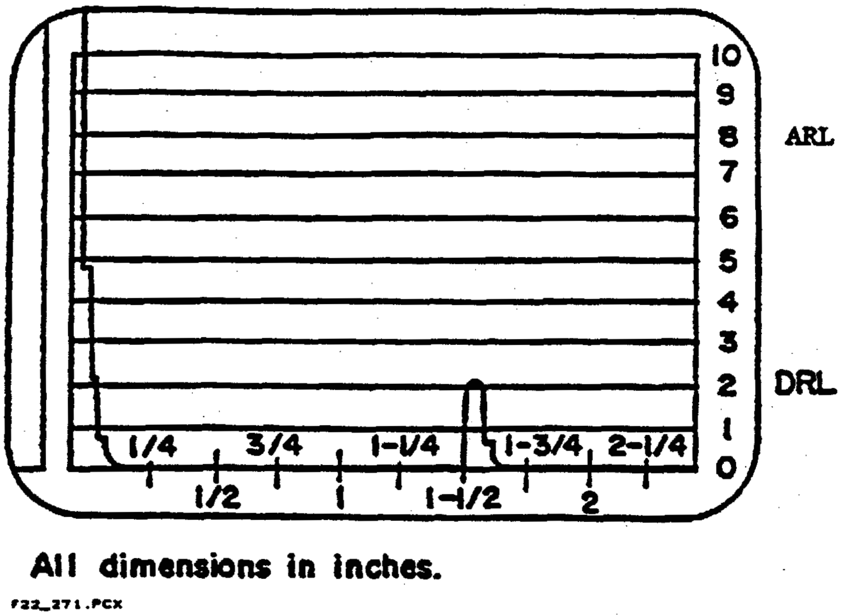


FIGURE 20. Typical viewing screen calibration (butt welds) (with db control).

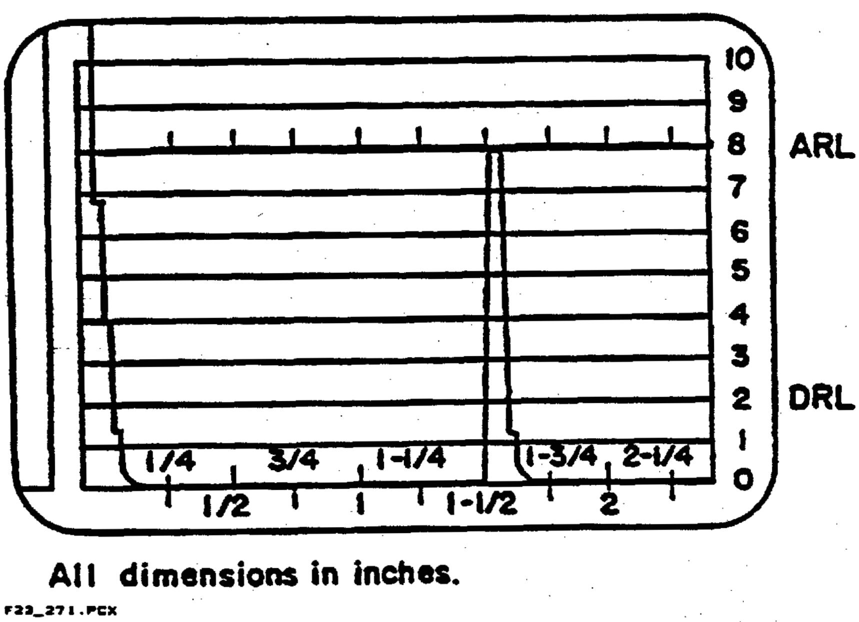


FIGURE 21. Typical viewing screen calibration (butt welds) (without db control).

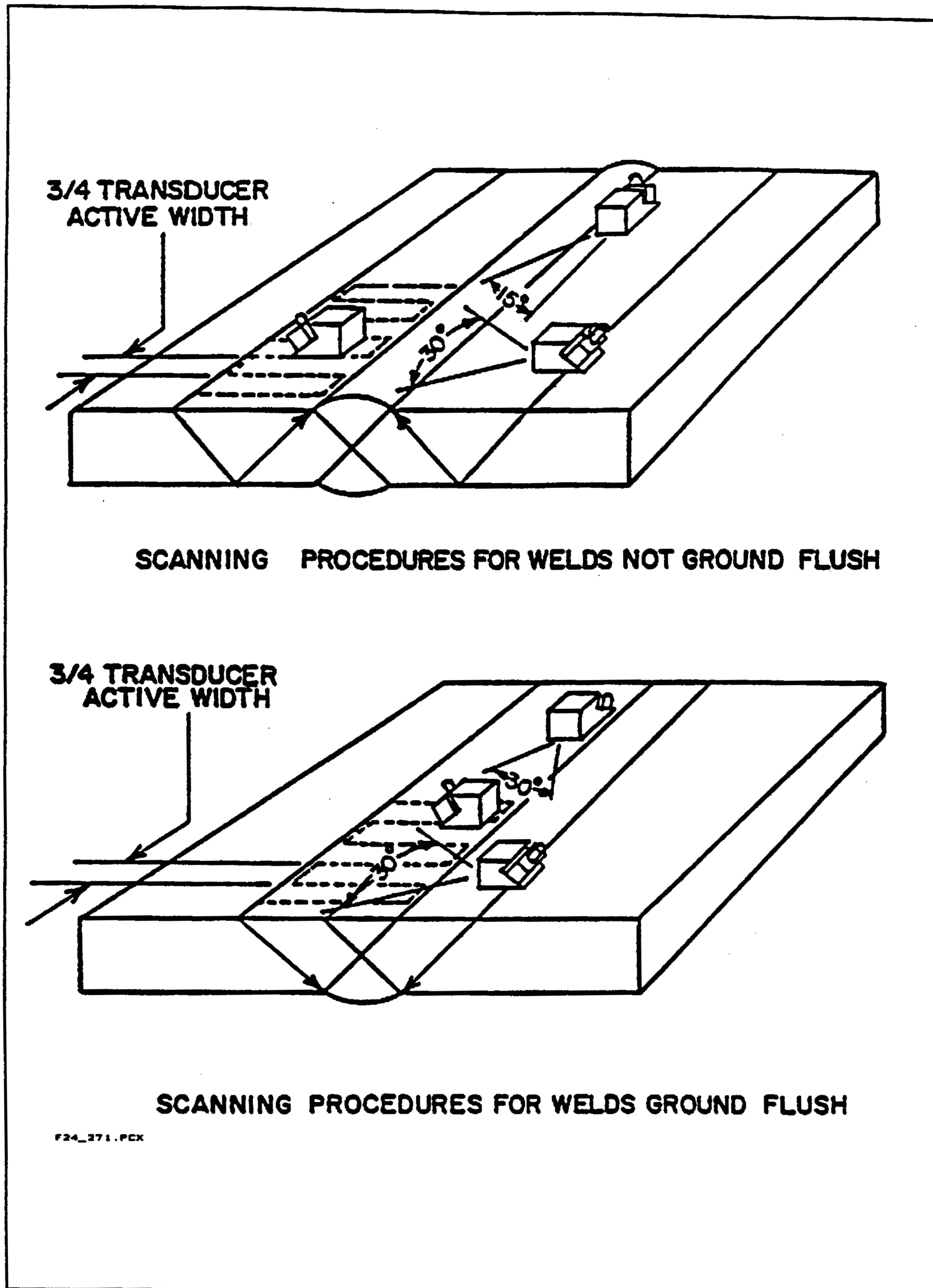
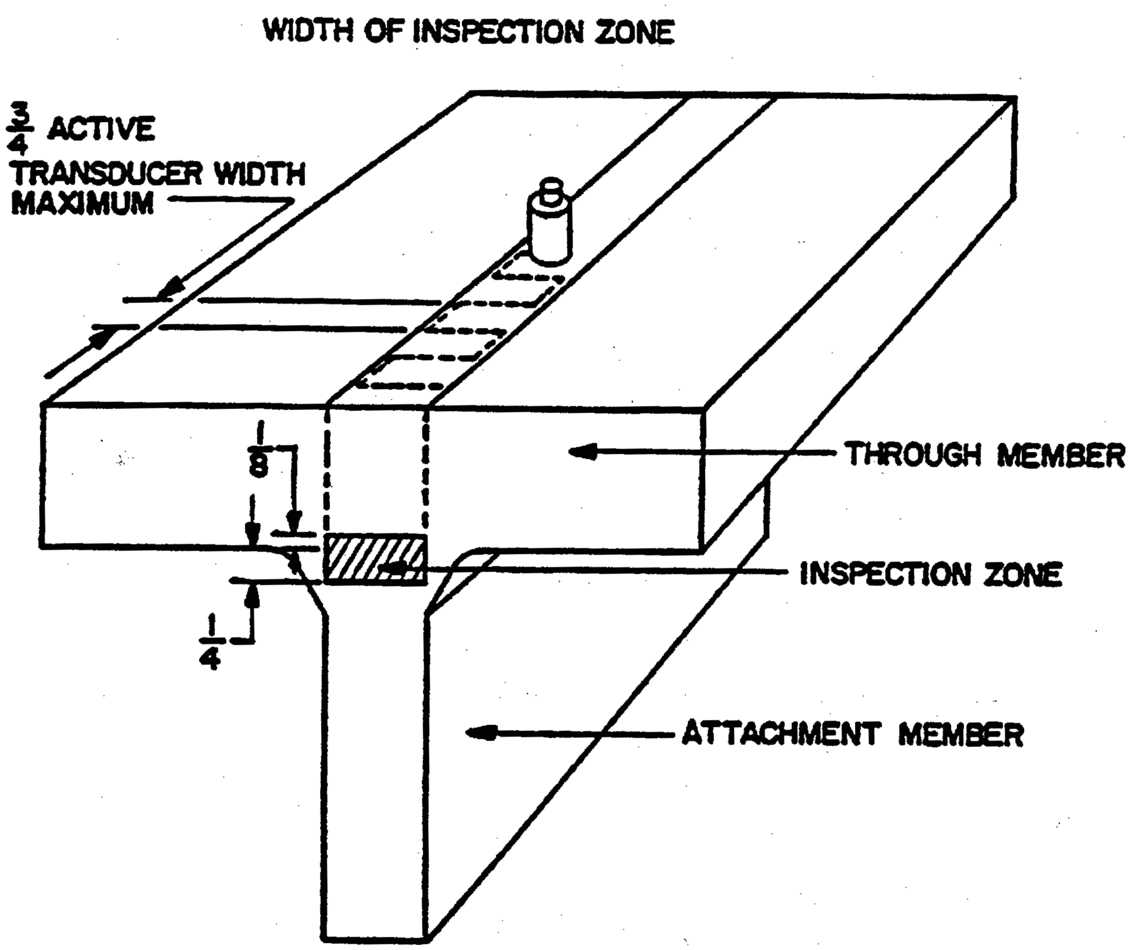


FIGURE 22. Scanning procedures for welds.



All dimensions in inches.

F23_271.PCX

FIGURE 23. Scanning procedure for tee welds.

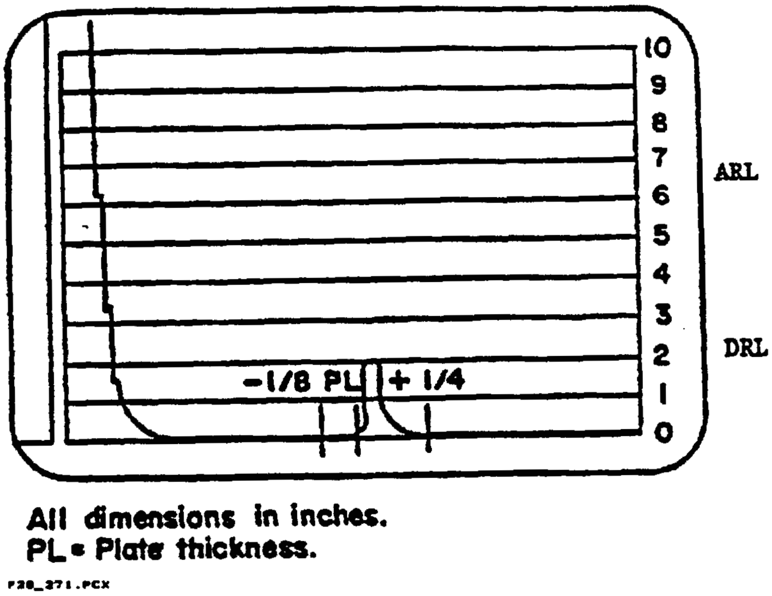


FIGURE 24. Typical viewing screen calibration (tee welds) (with db control).

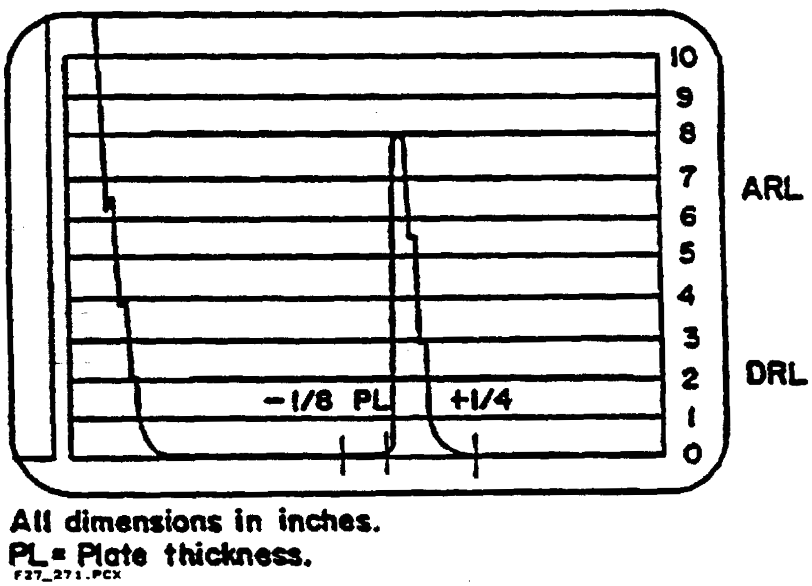
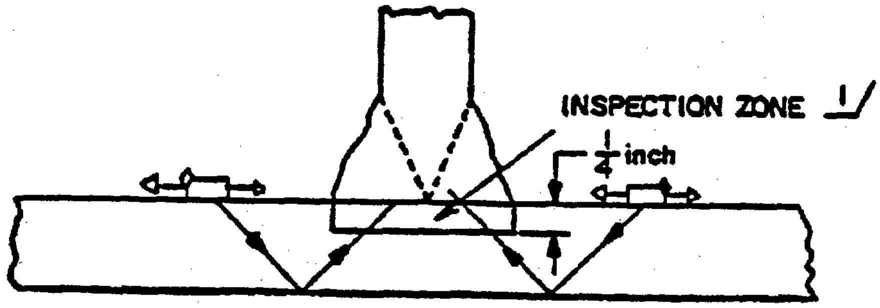


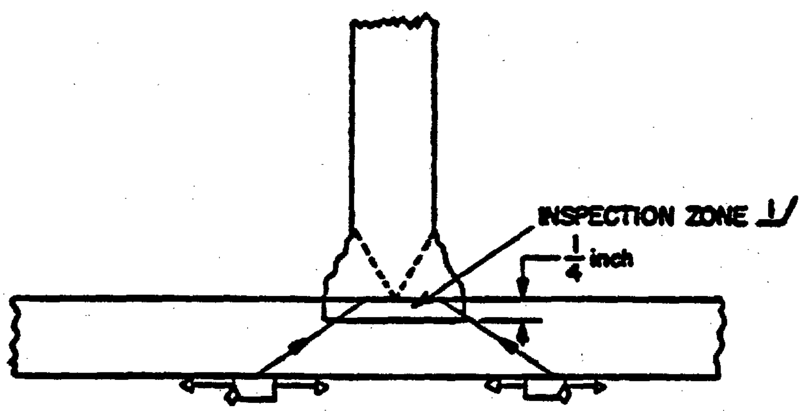
FIGURE 25. Typical viewing screen calibration (tee welds) (without db control).



F28_271.PCX

1/ THE INSPECTION ZONE MAY BE EXPANDED AS NECESSARY WITHIN THE PLATE WELD. THE SAME SCANNING PROCEDURES MAY BE APPLIED TO PARTIAL PENE TEE WELDS.

FIGURE 26. Surface opposite attachment member not accessible.



1/ THE INSPECTION ZONE MAY BE EXPANDED AS NECESSARY WITHIN THE PLATE OR WELD. THE SAME SCANNING PROCEDURES MAY BE APPLIED TO PARTIAL PENETRATION TEE WELDS.

F28_271.PCX

FIGURE 27. Surface opposite attachment member accessible.

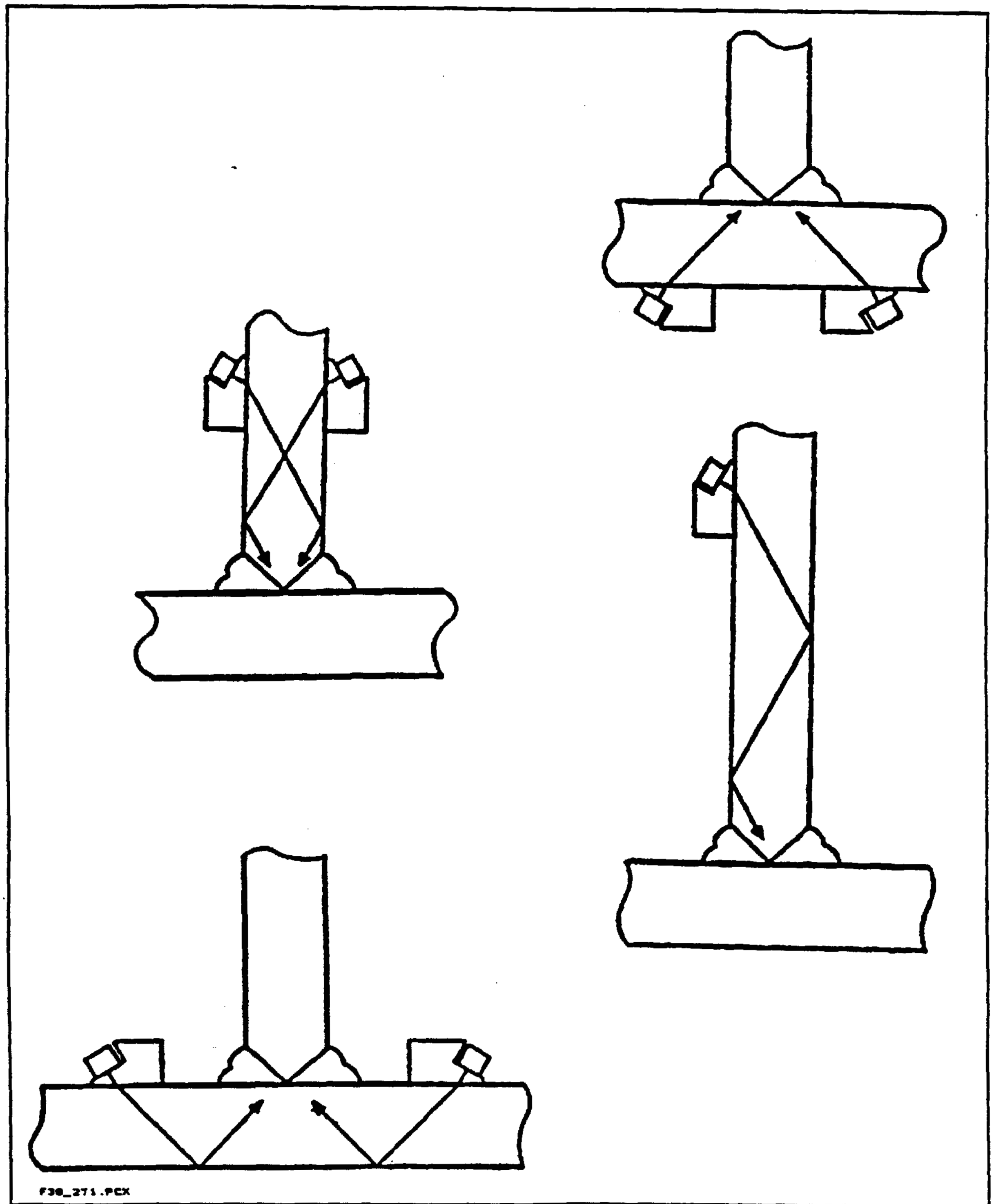


FIGURE 28. Accepted scanning techniques for tee welds.

ULTRASONIC WELD INSPECTION REPORT

1. SHIP		2. WELD IDENTIFICATION		DISCONTINUITIES							
3. FRAME	4. ☐PORT ☐STBD	5. STATION	6. ☐Bot. & ☐OTHER	7. NO.	DISTANCE 8. From A	9. From B	10. LNGTH	DEPTH 11. Min	12. Max	13. Ampl.	14. Beam Direct.	15. Accept or Rej
16. ☐FULL SKIP ☐COMP ☐HALF SKIP ☐OTHER		17. UT IN LIEU OF ☐MT ☐OTHER ☐RT ☐N/A									
INSPECTION SURFACE											
18. ☐ACCEPTABLE ☐UNACCEPTABLE		19. PROBED FROM ☐INSIDE ☐OTHER ☐OUTSIDE									
20. PLATE MATERIAL		21. PLATE THK.	22. WELD WIDTH								
INSTRUMENT											
23. MANUFACTURER & MODEL NUMBER			24. SERIAL NO.								
TRANSDUCER											
25. FRQNCY	26. SIZE	27. SERIAL NO.	28. ANGLE								
29. COUPLANT		30. CALIBRATION STANDARD NO.									
31. TEST PROCEDURE		32. ACCEPTANCE STANDARD									
33. INSPECTED BY		34. REVIEWED BY		35. DATE	37. WELD LENGTH REQUESTED WELD LENGTH INSPECTED				38. ☐ ACCEPT ☐ REJECT		

39. WELD JOINT DETAIL ↑ ☐F (FORWARD, PORT, UPWARD) ☐A (AFT, STARBOARD, DOWNWARD)

40. REMARKS

FIGURE 29. Ultrasonic weld inspection record.

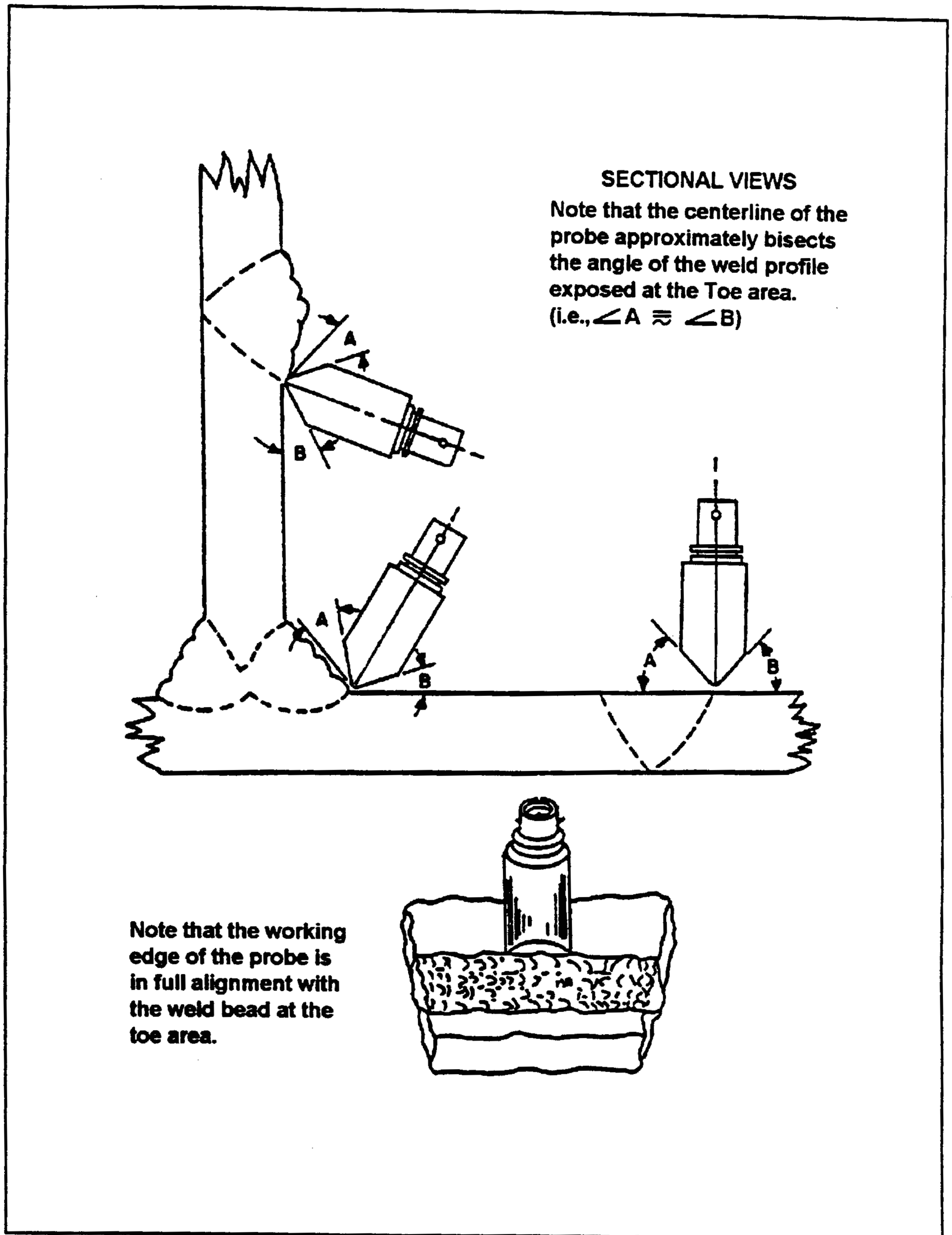


FIGURE 30. Recommended probe-to-weld attitude for eddy current standardization and scanning operations.