INTERNATIONAL

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Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels[1]

This standard is issued under the fixed designation E1067/E1067M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers acoustic emission (AE) examination or monitoring of fiberglass-reinforced plastic (FRP) tanks-vessels (equipment) under pressure or vacuum to determine structural integrity.

1.2 This practice is limited to tanks-vessels designed to operate at an internal pressure no greater than 1.73 MPa absolute [250 psia, 17.3 bar] above the static pressure due to the internal contents. It is also applicable for tanks-vessels designed for vacuum service with differential pressure levels between 0 and 0.10 MPa [0 and 14.5 psi, 1 bar].

1.3 This practice is limited to tanks-vessels with glass contents greater than 15 % by weight.

1.4 This practice applies to examinations of new and in-service equipment.

1.5 *Units*—The values stated in either SI units or inch-pound units are to be regarded as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D883 Terminology Relating to Plastics
D5436 Specification for Cast Poly(Methyl Methacrylate) Plastic Rods, Tubes, and Shapes
E543 Specification for Agencies Performing Nondestructive Testing
E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors
E750 Practice for Characterizing Acoustic Emission Instrumentation
E1106 Test Method for Primary Calibration of Acoustic Emission Sensors
E1316 Terminology for Nondestructive Examinations
E2075 Practice for Verifying the Consistency of AE-Sensor Response Using an Acrylic Rod
E1781 Practice for Secondary Calibration of Acoustic Emission Sensors
E2374 Guide for Acoustic Emission System Performance Verification

2.2 *ANSI/ASNT Standards:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification[3]
ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel[3]

2.3 *AIA Standard:*

NAS-410 Certification and Qualification of Nondestructive Personnel (Quality Assurance Committee)[4]

2.4 *ISO Standard:*

ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.04 on Acoustic Emission Method.

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

[3] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

***A Summary of Changes section appears at the end of this standard**

3. Terminology

3.1 Complete definitions of terms related to plastics and acoustic emission will be found in Terminology D883 and E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *FRP*—fiberglass reinforced plastic, a glass-fiber polymer composite with certain mechanical properties superior to those of the base resin.

3.2.2 *operating pressure*—the pressure at the top of a vessel at which it normally operates. It shall not exceed the design pressure and it is usually kept at a suitable level below the setting of the pressure-relieving devices to prevent their frequent opening.

3.2.3 *pressure, design*—the pressure used in design to determine the required minimum thicknesses and minimum mechanical properties.

3.2.4 *processor*—a circuit that analyzes AE waveforms. (See Section 7 and A1.8.)

3.2.5 *summing amplifier (summer, mixer)*—an operational amplifier that produces an output signal equal to a weighted sum of the input signals.

3.2.6 *zone*—the area surrounding a sensor from which AE can be detected by that sensor.

4. Summary of Practice

4.1 This practice consists of subjecting equipment to increasing pressure or vacuum while monitoring with sensors that are sensitive to acoustic emission (transient stress waves) caused by growing flaws. The instrumentation and techniques for sensing and analyzing AE data are described.

4.2 This practice provides guidelines to determine the location and severity of structural flaws in FRP equipment.

4.3 This practice provides guidelines for AE examination of FRP equipment within the pressure range stated in 1.2. Maximum test pressure (or vacuum) for an FRP vessel will be determined upon agreement among user, manufacturer, or test agency, or a combination thereof. Pressure vessels will normally be tested to 1.1 × operating pressure. Atmospheric storage vessels and vacuum vessels will normally be tested under maximum operating conditions. Vessels will normally be tested at ambient temperature. In the case of elevated operating temperature the test may be performed either at operating or ambient temperature. The test temperature must be below the glass transition temperature of the resin.

5. Significance and Use

5.1 The AE examination method detects damage in FRP equipment. The damage mechanisms that are detected in FRP are as follows: resin cracking, fiber debonding, fiber pullout, fiber breakage, delamination, and bond failure in assembled joints (for example, nozzles, manways, and so forth). Flaws in unstressed areas and flaws that are structurally insignificant will not generate AE.

5.2 This practice is convenient for on-line use under operating stress to determine structural integrity of in-service equipment usually with minimal process disruption.

5.3 Indications located with AE should be examined by other techniques; for example, visual, ultrasound, dye penetrant, and so forth, and may be repaired and tested as appropriate. Repair procedure recommendations are outside the scope of this practice.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice:

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

6.4 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be in accordance with 9.2 unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 13 unless otherwise specified. Since acceptance criteria are not specified in this practice, they shall be specified in the contractual agreement.

7. Instrumentation

7.1 The AE instrumentation consists of sensors, signal processors, and recording equipment. Additional information on AE instrumentation can be found in Practice E750.

7.2 Instrumentation shall be capable of recording AE hits, signal strength and hit duration and have sufficient channels to localize AE sources in real time. It may incorporate (as an option) peak-amplitude detection for each input channel or for groups of channels. Hit detection is required for each channel. An AE hit amplitude measurement is recommended for sensitivity verification (see Annex A2). Amplitude distributions are recommended for flaw characterization. It is preferred that AE instrumentation acquire and record duration hit and amplitude information on a per channel basis. The AE instrumentation is further described in Annex A1.

7.3 Capability for measuring parameters such as time and pressure shall be provided. The pressure-vacuum in the vessel should be continuously monitored to an accuracy of ±2 % of the maximum test value.

7.4 *Lockouts and Guard Sensors*—These techniques shall not be used.

7.5 *Instrument Displays*—- The instrumentation shall be capable of providing the following real time displays:

7.5.1 *Bar Chart by Channel of Cumulative Signal Strength*—Enables the examiner to identify which channel is recording the most data.

7.5.2 *Amplitude per Hit Versus Time*—Provides the examiner with early warning of an impending failure (see Reference (**1**)).

7.5.3 *Duration per Hit Versus Time*—Useful for identifying rubbing or sliding (see Reference (**1**)).

7.5.4 *Log Duration (or Counts) per Hit Versus Amplitude per Hit*—Helps the examiner determine the presence of false emission signals (see Reference (**1**)).

7.5.5 *Cumulative Signal Strength per Channel Versus Time*—Useful for identifying certain types of instrument malfunctions; for example, continuous electronic noise will produce a characteristically steady rise with time, unlike the stepwise rise associated with natural AE.

7.6 *Cumulative Amplitude Distribution,* or a tabular listing by channel number of total hits equal to and greater than defined amplitude values. Tabular amplitude values shall be in increments of not greater than 5 dB and shall be for at least a 35 dB range beginning at the threshold. These displays are used to provide warning of significant fiber breakage of the type that can lead to sudden structural failure. The displays also provide information about the micromechanisms giving rise to the emission and warn of potential instrument malfunction.

8. Examination Preparations

8.1 *Safety*—All plant safety requirements unique to the examination location shall be met.

8.1.1 Protective clothing and equipment that is normally required in the area in which the examination is being conducted shall be worn.

8.1.2 A fire permit may be needed to use the electronic instrumentation.

8.1.3 Precautions shall be taken to protect against the consequences of catastrophic failure when pressure testing, for example, flying debris and impact of escaping liquid. Pressurizing under pneumatic conditions is not recommended except when normal service loads include either a superposed gas pressure or gas pressure only. Care shall be taken to avoid overstressing the lower section of the vessel when liquid test loads are used to simulate operating gas pressures.

8.1.4 Special safety precautions shall be taken when pneumatic testing is required; for example, safety valves, and so forth.

8.2 *Vessel Conditioning*—The operating conditions for vessels that have been stressed previously shall be reduced prior to examining in accordance with the schedule shown in Table 1. Table 1 is used as follows. The planned reduced pressure is expressed as a percentage of the maximum operating pressure or load in the vessel during the past year (the latter must be known in order to conduct the AE examination properly). Looking for this percentage in the first column of Table 1, the corresponding row in the second column shows the time that must be spent at the reduced pressure, to condition the vessel prior to making an AE test. When the percentage falls between two values in the first column, the higher value is used.

TABLE 1 Requirements for Reduced Operating Pressure-Load Immediately Prior to Examining

% of Operating Pressure or Load, or Both	Time at Reduced Pressure or Load, or Both
10 or less	12 h
20	18 h
30	30 h
40	2 days
50	4 days
60	7 days

8.3 *Vessel Stressing*—Arrangements should be made to stress the vessel as prescribed in 4.3. The stress rate shall be sufficient to expedite the examination with minimum extraneous noise. Holding stress levels is a key aspect of an acoustic emission examination. Accordingly, provision must be made for holding the pressure-load at designated check points.

8.3.1 *Atmospheric Tanks*—Process liquid is the preferred fill medium for atmospheric tanks. If water must replace the process liquid, the designer and user shall be in agreement on the procedure to achieve acceptable stress levels.

8.3.2 *Vacuum-Tank Stressing*—A controllable vacuum-pump system is required for vacuum tanks.

8.3.3 *Pressure-Vessel Stressing*—Water is the preferred medium for pressure tanks. Safe means for hydraulically increasing the pressure under controlled conditions shall be provided.

8.4 *Tank Support*—The tank shall be examined in its operating position and supported in a manner consistent with good installation practice. Flat-bottomed tanks examined in other than the intended location shall be mounted on a pad (for example, rubber on a concrete base or equivalent) to reduce structure-borne noise between the tank and base.

8.5 *Environmental*—The normal minimum acceptable vessel wall temperature is 4°C [40°F].

8.6 *Noise Reduction*—Noise sources in the examination frequency and amplitude range, such as rain, spargers, and foreign objects contacting the tank, must be minimized since they mask the AE signals emanating from the structure. The inlet should be at the lowest nozzle or as near to the bottom of the vessel as possible, that is, below the liquid level. Liquid falling, swirling, or splashing can invalidate data obtained during the filling phase. However, this needs to be addressed by appropriate data filtering, not by turning off data acquisition during the filling phase altogether.

8.7 *Power Supply*—A stable grounded power supply, meeting the specification of the instrumentation, is required at the examination site.

8.8 *Instrumentation Settings*—Settings will be determined as described in Annex A2.

9. Sensors

9.1 *Sensor Mounting*—Refer to Practice E650 for additional information on sensor mounting. Location and spacing of the sensors are discussed in 9.4. Sensors shall be placed in designated locations with a couplant between the sensor and examination article. One recommended couplant is silicone-stopcock grease. Care must be exercised to assure that adequate couplant is applied. Sensors shall be held in place utilizing methods of attachment which do not create extraneous signals. Methods of attachment using crossed strips of pressure-sensitive tape or suitable adhesive systems, may be considered. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated. The attachment method should provide support for the signal cable (and preamplifier) to prevent the cable(s) from stressing the sensor or pulling the sensor away from the examination article causing loss of coupling.

9.2 *Surface Contact*—Reliable coupling between the sensor and tank surface shall be assured and the surface of the vessel in contact with the sensor shall be clean and free of particulate matter. Sensors should be mounted directly on the tank surface unless integral waveguides shown by test to be satisfactory are used. Preparation of the contact surface shall be compatible with both sensor and structure modification requirements. Possible causes of signal loss are coatings such as paint and encapsulants, surface curvature, and surface roughness at the contact area.

9.3 *High-frequency and Low-frequency Channels*—See Annex A1, subsections A1.1.2 and A1.1.3 for specifications of high-frequency and low-frequency sensors. High-frequency channels are used with zone location for the purpose of identifying and evaluating emission sources that may represent defects. All evaluation of AE sources shall be conducted using high-frequency channels. Low-frequency channels can detect sources over a greater distance. They may optionally be used on large vessels when coverage of the whole vessel with high-frequency channels would be uneconomical. When both kinds of sensor are used, high-frequency sensors are placed to cover the higher-risk/higher-stress regions of the vessel (for example, shell to base transition, manways, nozzles). Low-frequency sensors are placed in lower-risk regions (for example, shell sections remote from structural discontinuities) where there is a lower probability of active AE sources being present. If significant activity detected on low-frequency channels is not detected simultaneously on high-frequency channels, the adequacy of high-frequency sensor location shall be assessed by the examiner. High-frequency channels may be added or relocated and loading repeated after reconditioning of the vessel, as necessary, for conclusive examination of the emissive areas indicated by the low-frequency channels. In this manner, the low-frequency channels are used to ensure adequacy of the vessel coverage by high-frequency channels. Caution should be exercised in the use of low-frequency sensors, considering the adequacy of vessel coverage for final evaluation, and considering that low-frequency channels are more vulnerable to background noise, waves travelling across the liquid from remote locations, and so forth.

9.4 *Locations and Spacings*—Locations on the vessel shell are determined by the need to detect structural flaws at critical sections; for example, high-stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. Spacings are governed by the attenuation of the FRP material.

9.4.1 *Attenuation Characterization*—Typical signal propagation losses shall be determined in accordance with the following procedure. This procedure provides a relative measure of the attenuation, but may not be representative of genuine AE activity. It should be noted that the peak amplitude from a mechanical pencil lead break may vary with surface hardness, resin condition, and cure. The attenuation characterization should be made above the liquid line.

9.4.1.1 Select a representative region of the vessel away from manways, nozzles, and so forth. Mount an AE sensor and locate points at distances of 150 mm [6 in.] and 300 mm [12 in.] from the center of the sensor along a line parallel to one of the principal directions of the surface fiber (if applicable). Select two additional points on the surface of the vessel at 150 mm [6 in.] and 300 mm [12 in.] along a line inclined 45° to the direction of the original points. At each of the four points, break 0.3 mm 2H leads[5] and record peak amplitude. All lead breaks shall be done at an angle of approximately 30° to the surface with a 2.5 mm [0.1 in.] lead extension. The data shall be retained as part of the original experimental record.

9.4.2 *Sensor Spacings*—The recommended sensor spacing on the vessel shall not be greater than 3 × the distance at which detected signals from the attenuation characterization equal the threshold setting.

9.4.3 *Sensor Location*—Sensor location guidelines for the following tank types are given in the Annex. Other tank types require an agreement among the owner, manufacturer, or examination agency, or combinations thereof.

9.4.3.1 *Case I: Atmospheric Vertical Tank*—flat bottom, flanged and dished head, typical nozzle and manway configuration, cylindrical shell fabricated in two sections with secondary bond-butt joint, dip pipe.

9.4.3.2 *Case II: Atmospheric Vertical Tank*—flat bottom, 2:1 elliptical head, typical nozzle and manway configuration, agitator with baffles, cylindrical shell fabricated in one section.

9.4.3.3 *Case III: Atmospheric-Pressure Vertical Tank*—flanged and dished heads top and bottom, typical nozzle and manway configuration, packing support, legs attached to cylindrical shell, cylindrical shell fabricated in one section.

9.4.3.4 *Case IV: Atmospheric-Pressure Vertical Tank*—cone bottom, 2:1 elliptical head, typical nozzle and manway configuration, cylindrical shell fabricated in two sections, body flange, dip pipe, support ring.

9.4.3.5 *Case V: Atmospheric-Vacuum Vertical Tank*—flanged and dished heads top and bottom, typical nozzle and manway configuration, packing support, stiffening ribs, support ring, cylindrical shell fabricated in two sections with secondary bond-butt joint.

9.4.3.6 *Case VI: Atmospheric-Pressure Horizontal Tank*—flanged and dished heads, typical nozzle and manway configuration, cylindrical shell fabricated in two sections with secondary bond-butt joint, saddle supports.

[5] Pentel 0.3-mm (2H) lead or its equivalent has been found satisfactory for this purpose.

10. Instrumentation System Performance Check

10.1 *Sensor Coupling and Circuit Continuity Verification*—Verification shall be performed following sensor mounting and system setup. The response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source (for example, pencil lead break) shall be recorded and evaluated prior to the examination (see Guide E2374).

10.1.1 The peak amplitude of the simulated event at a specific distance from each sensor should not vary more than 6 dB from the average of all the sensors. Any sensor-preamplifier combination failing this check should be investigated and replaced or repaired as necessary.

10.1.2 After the initial condition of each installed channel has been verified as satisfactory per the preceding paragraphs, a global check such as automatic sensor test (AST) should be performed to furnish a baseline for whatever post test and interim checks are planned (see 10.3). AST, though less comprehensive than pencil lead break technique, takes much less time to perform.

10.2 *Background Noise Check*—A background noise check is recommended to identify and determine the level of spurious signals. This is done following the completion of the verification described in 10.1 and prior to stressing the vessel. A recommended time period is 20 minutes.

10.3 *Post Test and Interim Checks*—After completion of the loading/monitoring, a check should be conducted to verify the stability of channel performance, in particular the continuing integrity of sensor mounting and coupling. This can be accomplished by repeating a global check such as AST, see 10.1.2. Interim tests of this kind can also be employed in unusual situations such as lengthy test interruptions, to confirm the ongoing integrity of the monitoring setup. In the event that these tests show one or more channels to have become ineffective, corrective measures shall be taken and/or consideration shall be given to the status of the affected zone(s) relative to the goals of the inspection.

11. Examination Procedure

11.1 *General Guidelines*—The tank-vessel is subjected to programmed increasing pressure-load levels to a predetermined maximum while being monitored by sensors that detect acoustic emission (stress waves) caused by growing structural flaws.

11.1.1 Fill and pressurization rates shall be controlled so as not to exceed a strain rate of 0.005 % per min based on calculated values or actual strain gage measurements of principal strains. Normally, the desired pressure will be attained with a liquid (see 8.1.3 and 8.1.4). Pressurization with a gas (air, N_2 and so forth) is not recommended. A suitable manometer or other type gage shall be used to monitor pressure.

11.1.2 Vacuum should be attained with a suitable vacuum source. A quick release valve shall be provided to handle any imminent catastrophic failure condition.

11.1.3 Background noise shall be minimized and identified (see also 8.6). Excessive background noise is cause for suspension of the pressurization. In the analysis of examination results, background noise should be properly discounted. Sources of background noise include the following: liquid splashing into a tank, a fill rate that is too high, pumps, motors, agitators and other mechanical devices, electromagnetic interference, and environmental factors, such as rain, wind, and so forth.

11.2 *Loading*—Atmospheric tanks that operate with liquid head and superimposed pressures of 0.2 MPa [30 psia, 2 bars] or less, and vacuum vessels that operate at pressures below atmospheric, shall be loaded in a series of steps. Recommended load procedures are shown in Fig. 1 and Fig. 2. The algorithm flow chart for this class of tanks is given in Fig. 3.

11.2.1 For tanks that have been stressed previously, the examination can begin with the liquid level as high as 60 % of the operating or maximum test level (see 8.2). Fig. 1 should be modified for vessels that are partially full at the beginning of an examination. The background noise baseline determination is important for this class of examination and should be provided for. Many vessels operate with liquid contents and partial vacuum; however, vacuum vessels are normally examined empty.

11.2.2 Pressure vessels that operate with superimposed pressures greater than 0.2 MPa [30 psia] shall be loaded in a series of pressurize-and-hold, depressurize-and-hold steps as shown in Fig. 4. The depressurize-and-hold steps in this schedule may be eliminated if no emission has been detected in the previous pressurize-and-hold steps. Prior to loading, pressure vessels shall be conditioned as described in 8.2. AE monitoring of the first loading of new pressure vessels is optional, since they may be too noisy to meet the acceptance criteria; however, first loading data can have value as a baseline and indicator of long-term performance. In case a new vessel is not monitored during its first loading, or in case it is monitored and does not meet the evaluation criteria, then it is reconditioned in accordance with 8.2, reloaded with AE monitoring and evaluated against the "subsequent loading" criteria (see Table X1.2). The algorithm flow chart for this class of tanks is given in Fig. 5.

11.2.3 The initial hold period is used to determine a baseline of the background noise. This data provides an estimate of the total background noise contribution during the examination. Background noise shall be discounted in the final data analysis.

11.2.4 Intermittent load holds shall be for 4 min. As shown in Fig. 4, pressure vessels shall be loaded in steps up to 30 % of the maximum test pressure. Thereafter, the pressure shall be decreased by 10 % of the maximum test pressure before proceeding to the next hold level. Following a decrease in pressure, the load shall be held for 4 min before reloading.

11.2.5 For all vessels, the final load hold shall be for 30 min. The vessel should be monitored continuously during this period.

11.3 *Felicity Ratio Determination*—The Felicity ratio is not measured during the first loading of atmospheric tanks and vacuum vessels. The Felicity ratio is obtained directly from the ratio of the stress at the emission source at onset of significant emission and the maximum prior stress at the same point.

11.3.1 The Felicity ratio is measured from the unload-reload cycles during the first loading of pressure vessels. For subsequent loadings, the Felicity ratio is obtained directly from the

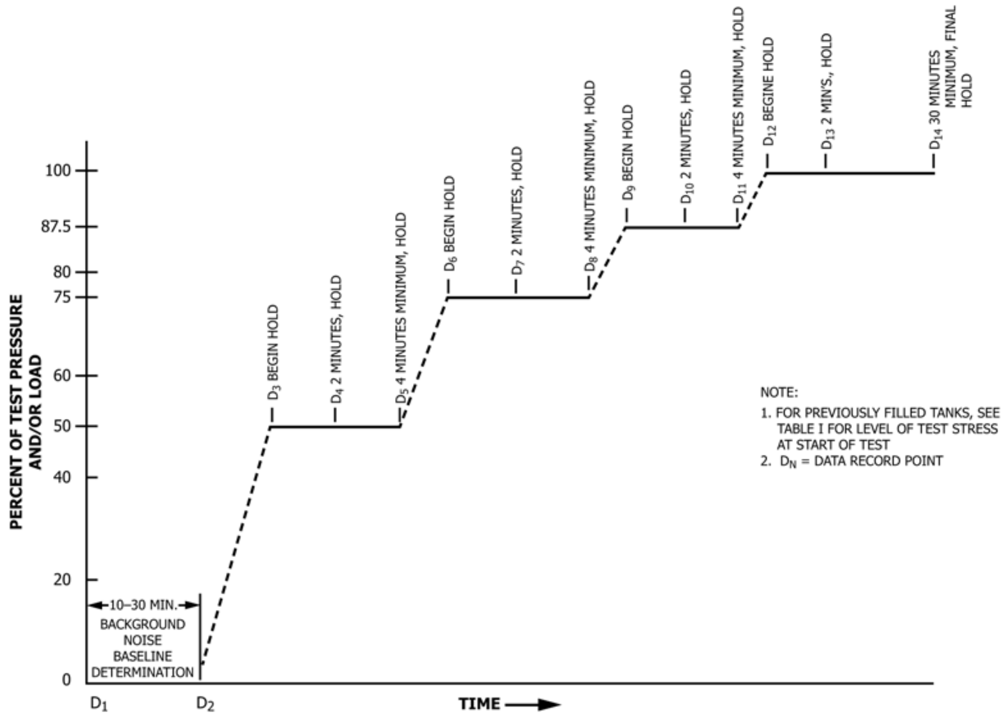

FIG. 1 Atmospheric Tank Examination, Stressing Sequence

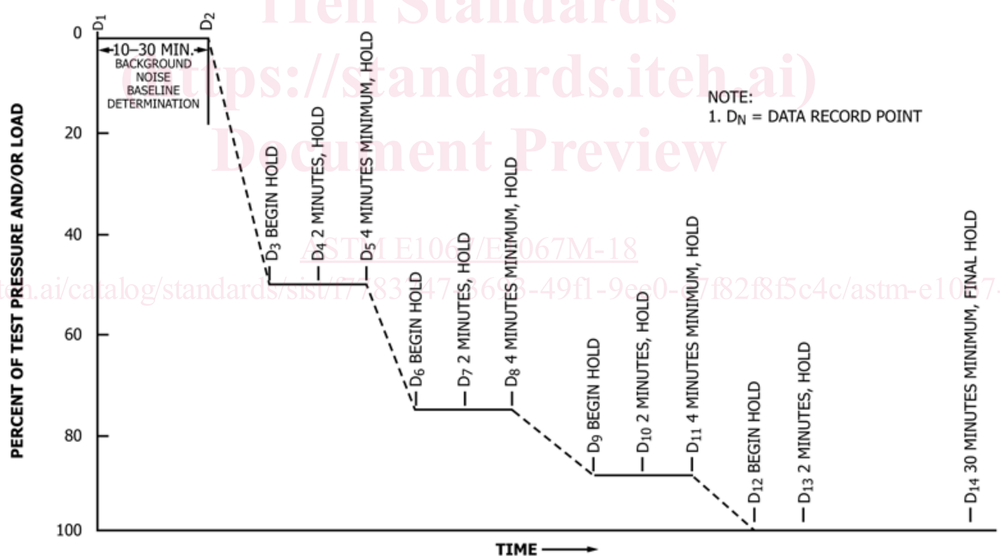

FIG. 2 Vacuum Tank Examination, Stressing Sequence

ratio of the stress at the emission source at onset of emission and the previous maximum stress at the same point. A secondary Felicity ratio is determined from the unload-reload cycles.

11.4 *Data Recording*—Prior to an examination, the signal propagation loss (attenuation) data, that is, amplitude as a function of distance from the signal source, shall be recorded in accordance with the procedure detailed in 9.4.

11.4.1 The number of hits from all channels whose amplitude exceeds the threshold setting shall be recorded. Channels that are active during load holds should be noted.

12. Interpretation of Results

12.1 *Examination Termination*—The real-time instrument displays shall be continuously monitored during the test. If any of these displays indicates approaching failure, the vessel shall