Designation: E 1067 – 96

An American National Standard

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

This standard is issued under the fixed designation E 1067; 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 0.44 MPa absolute (65 psia) 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 0.06 MPa (0 and 9 psi).

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 The values stated in SI units are to be regarded as standard. The inch-pound units in parentheses may be approximate.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (For more specific safety precautionary information see 8.1.)

2. Referenced Documents

2.1 *ASTM Standards:*

D 883 Terminology Relating to Plastics[2]

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing[3]

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors[3]

E 750 Practice for Characterizing Acoustic Emission Instrumentation[3]

E 1316 Terminology for Nondestructive Examinations[3]

2.2 *ANSI/ASNT Standards:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification[4]

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel[4]

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification[5]

3. Terminology

3.1 Complete definitions of terms related to plastics and acoustic emission will be found in Terminology D 883 and E 1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *count value* N_c—an evaluation criterion based on the total number of AE counts. (See A2.4 of Annex A2.)

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

3.2.3 *high-amplitude threshold*—a threshold for large amplitude AE events. (See A2.3 of Annex A2.)

3.2.4 *low-amplitude threshold*—the threshold above which AE counts (N) are measured. (See A2.2 of Annex A2.)

3.2.5 *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.

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

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

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

3.2.9 *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

[1] This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.04 on Acoustic Emission.

Current edition approved July 10, 1996. Published September 1996. Originally published as E 1067 – 85. Last previous edition E 1067 – 89 (1991)$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 03.03.

[4] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

[5] Available from Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

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 having an internal operating pressure exceeding 0.2 MPa absolute (30 psia), will normally be tested to 1.5 × operating pressure. Atmospheric storage vessels will normally be tested under maximum operating conditions. Pressure vessels having an internal pressure between 0.1 and 0.2 MPa absolute (15 and 30 psia), and vacuum vessels having an external differential pressure between 0 and 0.06 MPa (0 and 9 psi), will normally be tested to pressures in the range from 1.0 to 1.5 × operating pressure.

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

6. Basis of Application

6.1 *Personnel Qualification*—NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL-STD-410, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated in accordance with Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6.3 *Procedures and Techniques*—The procedures and techniques to be utilized shall be in accordance with this practice unless otherwise specified. Specific techniques may 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 E 750.

7.2 Instrumentation shall be capable of recording AE counts and AE hits above the low-amplitude threshold, AE hits above the high-amplitude threshold within specific frequency ranges, and having 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 count, 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.

8. Test Preparations

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

8.1.1 Protective clothing and equipment that is normally required in the area in which the test 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, etc.

8.2 *Vessel Conditioning*—The operating conditions for vessels that have been stressed previously shall be reduced prior to testing according to the schedule shown in Table 1. The maximum operating pressure or load in the vessel during the past year must be known in order to conduct the AE examination properly.

8.3 *Vessel Stressing*—Arrangements should be made to stress the vessel to the operating pressure-load where possible. The stress rate shall be sufficient to expedite the test 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.

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

% 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

8.3.1 *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 tested in its operating position and supported in a manner consistent with good installation practice. Flat-bottomed tanks tested 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.

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

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

9. Sensors

9.1 *Sensor Mounting*—Refer to Practice E 650 for additional information on sensor mounting. Location and spacing of the sensors are discussed in 9.5. Sensors shall be placed in designated locations with a couplant between the sensor and test 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 test 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 Sensor*—(See Annex A1.) Several high-frequency channels are used for zone location of emission sources. Greater attenuation of stress waves at higher frequencies result in smaller zones of sensitivity for high-frequency sensors.

9.4 *Low-Frequency Sensor*—(See Annex A1.) Low-frequency channels are less affected by attenuation; therefore, they can be used to identify flaws in a large zone. If significant activity is detected on the low-frequency channels, and not on high-frequency channels, consideration should be given to relocating high-frequency sensors. It should be noted, however, that low-frequency channels are more susceptible to background noise.

9.5 *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.

9.5.1 *Attenuation Characterization*—Typical signal propagation losses shall be determined according to one of the following procedures. These procedures provide 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. In both cases the attenuation characterization should be made above the liquid line.

9.5.1.1 For acoustic emission instrumentation with amplitude analysis: Select a representative region of the vessel away from manways, nozzles, etc. Mount a high-frequency 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[6] 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.

9.5.1.2 *For Systems Without Amplitude Analysis*—Select a representative region of the vessel away from manways, nozzles, etc. Mount a high-frequency AE sensor and break 0.3 mm 2H leads along a line parallel to one of the principal directions of the surface fibers.

9.5.1.3 Record the distances from the center of the sensor to the points at which the high-amplitude threshold and lowamplitude threshold are no longer detected (see Annex A2). Repeat this procedure along a line inclined 45° to the direction of the original line. The data shall be retained as part of the original experimental record.

9.5.2 *Sensor Spacings*—The recommended high-frequency sensor spacing on the vessel shall be not greater than 3 × the distance at which detected signals from the attenuation characterization equal the low-amplitude threshold.

9.5.3 *Sensor Location*—Sensor location guidelines for the following tank types are given in the Annex. Other tank types

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

require an agreement among the owner, manufacturer, or test agency, or combinations thereof.

9.5.3.1 *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.

9.5.3.2 *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.

9.5.3.3 *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.

9.5.3.4 *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.

9.5.3.5 *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.

9.5.3.6 *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.

10. Instrumentation System Performance Check

10.1 *Sensor Coupling and Circuit Continuity Verification*—Verification shall be performed following sensor mounting and system hookup. The response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source should be taken prior to the examination.

10.1.1 When using systems with amplitude analysis, 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 When using systems without amplitude analysis, verification is accomplished by recording the distance from each sensor at which the response from the repeated simulated source falls below the low-amplitude threshold. This distance should not vary more than 30 cm (12 in.) from the average of all sensors. Any sensor-preamplifier combination failing this check should be investigated and replaced or repaired as necessary.

10.2 *Background Noise Check*—Recommended to identify and determine 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 10 to 30 min.

11. Test 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 %/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 etc.) 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, etc.

11.2 *Loading*—Atmospheric tanks that operate with liquid head and pressures of 0.2 MPa (30 psia) 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 as shown in Fig. 4. 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

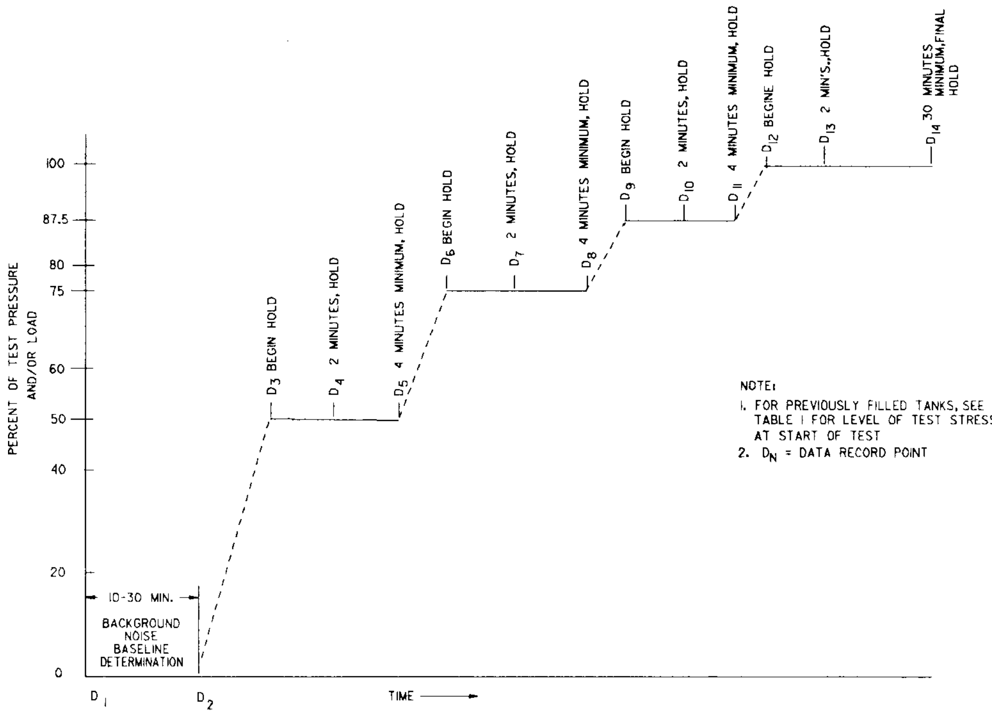

FIG. 1 Atmospheric Tank Test, Stressing Sequence

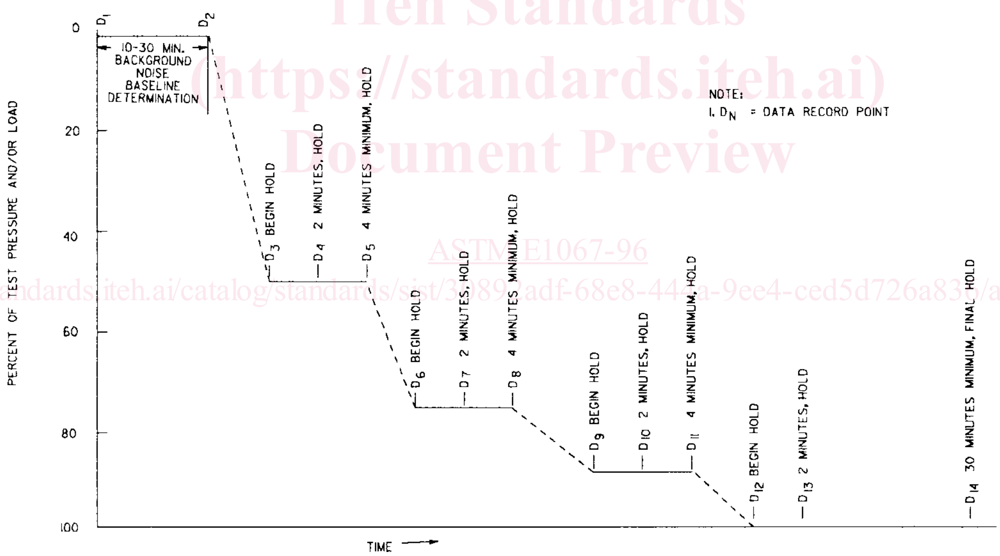

FIG. 2 Vacuum Tank Test, Stressing Sequence

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 9.5.

11.4.1 During an examination, the sum of counts above the low-amplitude threshold from all low-frequency channels shall be monitored and the sum of counts above the low-amplitude threshold from all the high-frequency channels shall be separately monitored and recorded. The number of hits from all high-frequency channels whose amplitude exceeds the high-amplitude threshold shall also be recorded (see Annex A2). Channels that are active during load holds should be noted.

12. Interpretation of Results

12.1 *Test Termination*—Departure from a linear count-load relationship should signal caution. If the AE count rate increases rapidly with load, the vessel shall be unloaded and the examination terminated. A rapidly (exponentially) increasing count rate indicates uncontrolled, continuing damage and is indicative of impending failure.

12.2 *Significance of Data*:

12.2.1 Evaluation based on emissions during load hold is

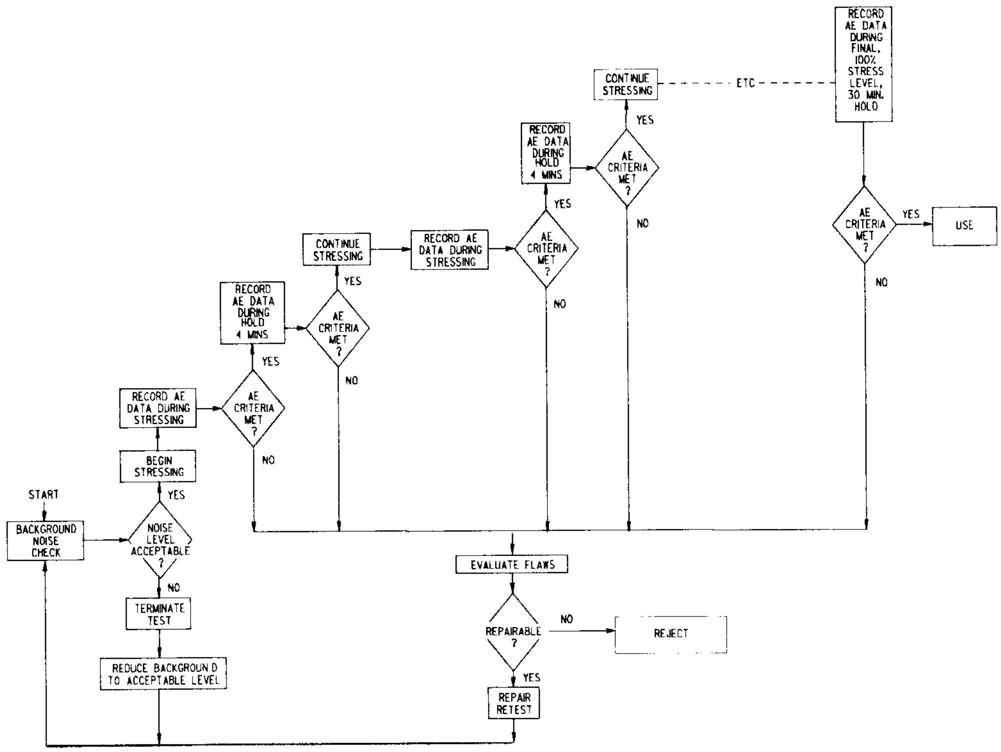

FIG. 3 AE Test Algorithm—Flow Chart Atmospheric-Vacuum Tanks (See Fig. 1 and Fig. 2.)

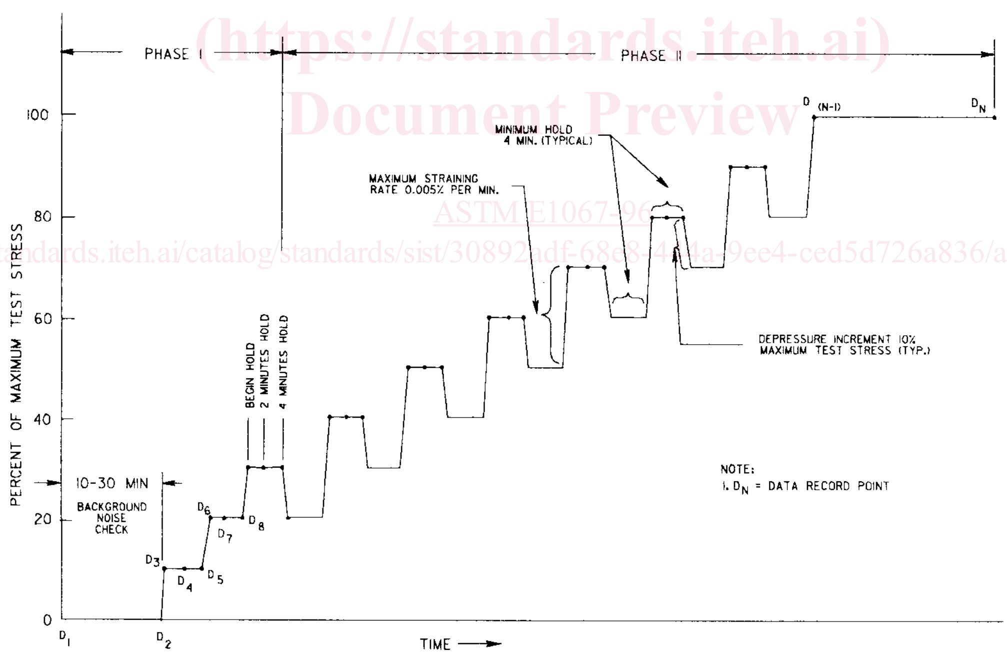

FIG. 4 Pressure Tank Test, Stressing Sequence

particularly significant. Continuing emissions indicate continuing damage. Fill and other background noise will generally be at a minimum during a load hold. Emissions continuing during hold periods is a condition on which acceptance criteria may be based.

12.2.2 Evaluation based on Felicity ratio is important for in-service vessels. The Felicity ratio provides a measure of the severity of previously induced damage. The onset of "significant" emission for determining measurement of the Felicity ratio is a matter of experience. The following are offered as guidelines to determine if emission is significant:

12.2.2.1 More than five bursts of emission during a 10 % increase in load.

12.2.2.2 More than N_c/25 counts during a 10 % increase in load, where N_c is the count value defined in Annex A2, Section A2.4.

12.2.2.3 Emission continues at a load hold. For purposes of this guideline, a short (1 min or less) nonprogrammed load