



Designation: E2191-02

## Standard Test Method for Designation: E 2191 – 08

### Standard Practice for Examination of Gas-Filled Filament-Wound Composite Pressure Vessels Using Acoustic Emission<sup>1</sup>

This standard is issued under the fixed designation E 2191; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

#### 1. Scope

1.1 This ~~test method~~ practice provides guidelines for acoustic emission (AE) examination of filament-wound composite pressure vessels, for example, the type used for fuel tanks in vehicles which use natural gas fuel.

1.2 This ~~test method~~ practice requires pressurization to a level equal to or greater than what is encountered in normal use. The tanks' pressurization history must be known in order to use this ~~test method~~ practice. Pressurization medium may be gas or liquid.

1.3 This ~~test method~~ practice is limited to vessels designed for less than ~~10000~~5000 psi (~~689~~(340 bar) maximum allowable working pressure and water volume less than 2.5 ft<sup>3</sup>(0.07 m<sup>3</sup>).

1.4 AE measurements are used to detect emission sources. Other nondestructive examination (NDE) methods may be used to ~~evaluate the significance of AE sources.~~ gain additional insight into the emission source. Procedures for other NDE methods are beyond the scope of this ~~test method~~ practice.

1.5 This ~~test method~~ practice applies to examination of new and in-service filament-wound composite pressure vessels.

1.6 This ~~test method~~ practice applies to examinations conducted at ambient temperatures above 70°F (21°C). This ~~test method~~ practice may be used at ambient temperatures below 70°F if provision has been made to fill to the tank's rated pressure at 70°F.

1.7 The values stated in inch-pound units are to be regarded as the standard. SI units which are in parentheses are for information only.

1.8 *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.* Specific precautionary statements are given in Section 8.

#### 2. Referenced Documents

##### 2.1 ASTM Standards:<sup>2</sup>

E 543 ~~Practice~~ Specification for Agencies Performing Nondestructive Testing

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E 1316 ~~Terminology for Nondestructive Examinations~~<sup>2</sup> Terminology for Nondestructive Examinations

E 2374 Guide for Acoustic Emission System Performance Verification

##### 2.2 Natural Gas Vehicle Standard:

American National Standard for Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers ANSI/AGA/NGV2<sup>3</sup>

##### 2.3 Compressed Gas Association Standard:

<sup>1</sup> This test method 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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<sup>2</sup> 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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<sup>3</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For Annual Book of ASTM Standards, Vol 03.03, volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

Pamphlet C-6.4, Methods for Visual Inspection of AGA NGV2 Containers<sup>4</sup>

2.4 U.S. Department of Transportation Reference:

NHTSA Federal Motor Vehicle Safety Standard No. 304, March 27, 1995<sup>5</sup>

2.5 ASNT Standards:

ANSI/ASNT CP-189, Standard for Qualification and Certification of Nondestructive Testing Personnel<sup>6</sup>

SNT-TC-1A, Recommended Practice for Nondestructive Testing Personnel Qualification and Certification<sup>6</sup>

### 3. Terminology

3.1 *Definitions*—See Terminology E 1316 for general terminology applicable to this ~~test method~~ practice.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *AE test pressure, n*—110 % of the greatest pressure ~~which that the test examination~~ article contains during previous service. Usually 125 % of the filling pressure is an acceptable AE ~~test examination~~ pressure. (Normally, gas is heated when compressed during the filling process; hence, tanks are filled to more than rated service pressure). After filling, pressure should settle to rated service pressure as gas temperature within the tank becomes equal to ambient temperature.

3.2.2 *detectability distance, n*—the maximum distance from a sensor at which a defined simulated AE source can be detected by the instrumentation with defined settings and using appropriate pressurization medium.

### 4. Summary of ~~Test Method~~ Practice

4.1 AE sensors are mounted on a vessel and emission is monitored while the vessel is pressurized to the “AE ~~test examination~~ pressure”.

4.2 This ~~test method~~ practice provides guidelines for the detection of AE from structural flaws in the composite overwrap in gas-filled, filament-wound composite pressure vessels. Damage mechanisms which produce AE include: resin cracking, fiber debonding, fiber pullout, fiber breakage, delamination and bond failure. Flaws in liner portions of a vessel may not be detected.

4.3 This ~~test method~~ practice and others found in ASTM, ASME, ASNT, SPI relate Acoustic Emission to applied load on the composite material. At relatively low load (safe operating conditions) the acoustic emission from the composite material is low. At higher loads (unsafe operating conditions) the slope of the AE versus load curve changes drastically. In some cases this phenomenon can be identified and quantified by a single AE parameter (that is, AE counts).

4.4 Structurally insignificant flaws or processes (for example, leaks) may produce emission.

4.5 This ~~test method~~ practice is convenient for periodic examination of vessels in-service.

4.6 Gas-filled filament-wound pressure vessels which exhibit unacceptable levels of AE should be examined by other methods; for example, visual, ultrasound, dye penetrant, etc., and may be repaired and re-examined in accordance with government regulations and manufacturers guidelines. Repair and repair examination procedures are outside the scope of this ~~test method~~ practice.

4.7 Any number of pressure vessels may be examined simultaneously as long as the appropriate number of sensors and instrumentation channels are used.

### 5. Significance and Use

5.1 Due to safety considerations, the Compressed Gas Association (CGA) and others have produced guidelines which address in-service inspection of NGV fuel containers (see 2.2-2.4). AE examination is listed as an alternative to the minimum three-year visual examination which generally requires that the container be removed from the vehicle to expose the entire container surface. The AE method allows “in-situ” examination of the container.

~~5.1.1 Slow-fill pressurization must proceed at flow rates that do not produce background noise from flow of the pressurizing medium. Acoustic emission data are recorded throughout a pressurization range (that is, 50% to 100% of AE test pressure).~~

~~5.1.2 Fast-fill pressurization can be used if hold periods are provided. Acoustic emission data are recorded only during the hold periods.~~

~~5.1.3 Background noise above the threshold will contaminate the AE data and render them useless. Users must be aware of the following common causes of background noise: high fill rate (measurable flow noise); mechanical contact with the vessel by objects; electromagnetic interference (EMI) and radio frequency interference (RFI) from nearby broadcasting facilities and from other sources; leaks at pipe or hose connections and airborne particles, insects, rain and snow. This test method should not be used if background noise cannot be eliminated or controlled.~~

5.1.1 Slow-fill pressurization must proceed at flow rates that do not produce background noise from flow of the pressurizing medium. Acoustic emission data are recorded throughout a pressurization range (that is, 50 % to 100 % of AE examination pressure).

<sup>4</sup> Available from Compressed Gas Association, 1725 Jefferson Davis Hwy, Suite 1004, Arlington, VA 22202-4102.

<sup>4</sup> Available from Compressed Gas Association (CGA), 4221 Walney Rd., 5th Floor, Chantilly, VA 20151-2923, <http://www.cganet.com>.

<sup>5</sup> Available from DODSSP, Bldg 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098.

<sup>5</sup> Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, <http://www.dodssp.daps.mil>.

<sup>6</sup> Available from American Society for Nondestructive Testing, P.O. Box 28518, 1711 Arlington Lane, Columbus, OH 43228-0518.

<sup>6</sup> Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, <http://www.asnt.org>.

5.1.2 Fast-fill pressurization can be used if hold periods are provided. Acoustic emission data are recorded only during the hold periods.

NOTE 1—Fast-fill pressurization is less appropriate for carbon (or graphite) composites due to the lower sensitivity of carbon fibers to stress rupture compared to other fibers.

5.1.3 Background noise above the threshold will contaminate the AE data and render them useless. Users must be aware of the following common causes of background noise: high fill rate (measurable flow noise); mechanical contact with the vessel by objects; electromagnetic interference (EMI) and radio frequency interference (RFI) from nearby broadcasting facilities and from other sources; leaks at pipe or hose connections and airborne particles, insects, rain and snow. This practice should not be used if background noise cannot be eliminated or controlled.

5.2 Sensitivity is influenced by factors that affect elastic wave propagation, sensor coupling and signal processor settings.

5.3 It is possible to measure AE from AE sources that cannot be verified by other NDE methods.

## 6. Basis of Application

6.1

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

6.2 Personnel Qualification—NDE personnel shall be qualified in accordance with a nationally recognized practice or standard such as ANSI/ASNT-CP-189—If specified in the contractual agreement, personnel performing examinations to this practice 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, or a similar document. The practice or standard used and its applicable revisions shall be specified in any contractual agreement between the using parties.

~~6.2, 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 Test Agencies—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6.3

6.4 Extent of Examination—The extent of examination shall be in accordance with 4.2 unless otherwise specified.

6.4

6.5 Reporting Criteria/Acceptance Criteria—Reporting criteria for the examination results shall be in accordance with Section 11 unless otherwise specified. Acceptance criteria shall be specified in the contractual agreement.

~~6.5 unless otherwise specified.~~

6.6 Personnel Training/Test Requirements—NDE personnel (examiner) shall be familiar with CGA Pamphlet C6 and shall have attended a training course and passed a written test which cover the following topics.

~~6.5.1 Basic technology of acoustic emission.~~

~~6.5.2 Failure mechanisms of reinforced plastics.~~

~~6.5.3 Acoustic emission instrumentation.~~

~~6.5.4 Instrumentation check out.~~

~~6.5.5 Vessel filling requirements.~~

~~6.5.6 Data collection and interpretation.~~

~~6.5.7 Test report.~~

6.6.1 Basic technology of acoustic emission.

6.6.2 Failure mechanisms of reinforced plastics.

6.6.3 Acoustic emission instrumentation.

6.6.4 Instrumentation verification.

6.6.5 Vessel filling requirements.

6.6.6 Data collection and interpretation.

6.6.7 Examination report generation.

## 7. Apparatus

7.1 Essential features of the apparatus required for this standard are shown in Fig. 1. Specifications are provided in Annex A1.

7.2 Couplant must be used to acoustically couple sensors to the vessel surface. Adhesives that have acceptable acoustic properties and traditional couplants are acceptable.

7.3 Sensors may be held in place with elastic straps, adhesive tape, or other mechanical means.

7.4 On small vessels (that is, where 100 % coverage can be achieved with two sensors) the sensor locations on the vessel wall will be determined by accessibility. Ideally they should be placed 180° apart at opposite ends of the container on the shoulders.

7.5 On larger vessels (that is, where two sensors cannot provide 100 % coverage) sensors are positioned on the vessel wall so as to provide complete coverage. Sensor spacings are governed by the attenuation of the material. If attenuation characteristics are not available from previous examinations of similar vessels follow the directions found below.

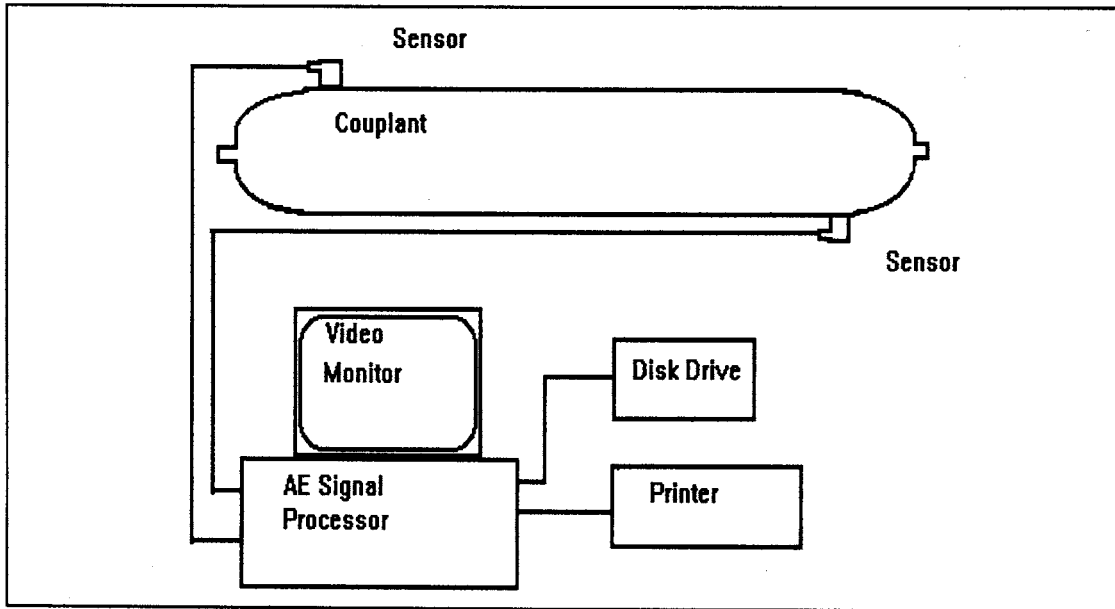


FIG. 1 Essential Features of the Apparatus

7.5.1 *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 a genuine AE source. It should be noted that peak amplitude caused by a mechanical pencil lead break may vary with surface hardness, resin condition and cure. Select a representative region of the vessel with clear access along the cylindrical section. Mount an AE sensor and mark off 6-in. intervals from the center of the sensor along a line parallel to the principal direction of the surface fiber. Select additional points on the surface of the vessel at 6-in. (15-cm) intervals along lines angled 45° and 90°, respectively, to the principal direction of the surface fiber. Break pencil leads (see Guide E 976) and record peak amplitude. All lead breaks shall be done at an angle of approximately 30° to the surface with a 0.1 in. (2.5 mm) lead extension. The attenuation data shall be retained as part of the test report.

7.5.2 Record the distances from the center of the sensor to the points where hits are no longer detected. Repeat this procedure along lines angled 45° and 90° to the direction of the original line. The data shall be retained as part of the test report. The minimum distance from the sensor at which the pencil lead break can no longer be detected is known as the detectability distance; this distance shall be recorded.

NOTE 2—Detectability distance may be reduced to achieve greater sensitivity to sources at farther distance.

7.5.3 Sensor spacing (distance between adjacent sensors) shall not be greater than 1.5 times the detectability distance.

7.6 AE sensors are used to detect stress waves produced by flaws. Sensors must be held in contact with the vessel wall to ensure adequate acoustic coupling.

7.7 A preamplifier may be enclosed in the sensor housing or in a separate enclosure. If a separate preamplifier is used, cable length, between sensor and preamplifier, must not result in a signal loss of greater than 3 dB [typically 6 ft (1.8 m) is acceptable].

7.8 Power/signal cable length (that is, cable between preamplifier and signal processor) shall not result in a signal loss of greater than 3 dB [typically 500 ft (150 m) is acceptable].

7.9 Signal processors are computerized instruments with independent channels that filter, measure and convert analog information into digital form for display and permanent storage. A signal processor must have sufficient speed and capacity to independently process data from all sensors simultaneously. The signal processor should provide capability to filter data for replay.

7.10 A video monitor is used to display processed data in various formats. Display format may be selected by the examiner.

7.11 A data storage device, such as a magnetic disk, is used to store data for replay or for archives.

7.12 Hard-copy capability should be available from a graphics/line printer or equivalent device.

## 8. Safety Precautions

8.1 Ambient temperature should not be below the ductile-brittle transition temperature of the pressure vessel liner.

## 9. Calibration and Standardization—Calibration and Verification

9.1 Annual calibration and verification of pressure transducer (if applicable), AE sensors, preamplifiers (if applicable), signal processor (particularly the signal processor time reference), and AE electronic waveform generator should be performed. Equipment should be adjusted so that it conforms to equipment manufacturer's specifications. Instruments used for calibrations must have current accuracy certification that is traceable to the National Institute for Standards and Technology (NIST).