Designation: E 1419 – 00

An American National Standard

Standard Test Method for Examination of Seamless, Gas-Filled, Pressure Vessels Using Acoustic Emission[1]

This standard is issued under the fixed designation E 1419; 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 test method provides guidelines for acoustic emission (AE) examinations of seamless pressure vessels (tubes) of the type used for distribution or storage of industrial gases.

1.2 This test method requires pressurization to a level greater than normal use. Pressurization medium may be gas or liquid.

1.3 This test method does not apply to vessels in cryogenic service.

1.4 The AE measurements are used to detect and locate emission sources. Other nondestructive test (NDT) methods must be used to evaluate the significance of AE sources. Procedures for other NDT techniques are beyond the scope of this test method. See Note 1.

NOTE 1—Shear wave, angle beam ultrasonic inspection is commonly used to establish circumferential position and dimensions of flaws that produce AE.

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

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.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings[2]

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

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

E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response[3]

E 1316 Terminology for Nondestructive Examinations[3]

2.2 *ASNT Standards:*[4]

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

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

2.3 *Code of Federal Regulations:*

Section 49, Code of Federal Regulations, Hazardous Materials Regulations of the Department of Transportation, Paragraphs 173.34, 173.301, 178.36, 178.37, and 178.45[5]

2.5 *Compressed Gas Association Standard:*

Pamphlet C-5 Service Life, Seamless High Pressure Cylinders[6]

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *fracture critical flaw*—a flaw that is large enough to exhibit unstable growth at service conditions.

3.2.2 *marked service pressure*—pressure for which a vessel is rated. Normally this value is stamped on the vessel.

3.2.3 *normal fill pressure*—level to which a vessel is pressurized. This may be greater, or may be less, than *marked service pressure*.

4. Summary of Test Method

4.1 The AE sensors are mounted on a vessel, and emission is monitored while the vessel is pressurized above normal fill pressure.

4.2 Sensors are mounted at each end of the vessel and are connected to an acoustic emission signal processor. The signal processor uses measured times of arrival of emission bursts to determine linear location of emission sources. If measured emission exceeds a prescribed level (that is, specific locations produce enough events), then such locations receive secondary (for example, ultrasonic) examination.

4.3 Secondary examination establishes presence of flaws

[1] 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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[2] *Annual Book of ASTM Standards*, Vol 01.05.

[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 Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

[6] Available from Compressed Gas Association, Inc., 1235 Jefferson Davis Highway, Arlington, VA 22202.

and measures flaw dimensions.

4.4 If flaw depth exceeds a prescribed limit (that is, a conservative limit that is based on construction material, wall thickness, fatigue crack growth estimates, and fracture critical flaw depth calculations), then the vessel must be removed from service.

5. Significance and Use

5.1 Because of safety considerations, regulatory agencies (for example, U.S. Department of Transportation) require periodic tests of vessels used in transportation of industrial gases (see Section 49, Code of Federal Regulations). The AE testing has become accepted as an alternative to the common hydrostatic proof test. In the common hydrostatic test, volumetric expansion of vessels is measured.

5.2 An AE test should not be used for a period of one year after a common hydrostatic test. See Note 2.

NOTE 2—The Kaiser effect relates to decreased emission that is expected during a second pressurization. Common hydrostatic tests use a relatively high test pressure (167 % of normal service pressure). (See Section 49, Code of Federal Regulations.) If an AE test is performed too soon after such a pressurization, the AE results will be insensitive to a lower test pressure (that is, the lower pressure that is associated with an AE test).

5.3 *Pressurization*:

5.3.1 General practice in the gas industry is to use low pressurization rates. This practice promotes safety and reduces equipment investment. The AE tests should be performed with pressurization rates that allow vessel deformation to be in equilibrium with the applied load. Typical current practice is to use rates that approximate 500 psi/h (3.45 MPa/h).

5.3.2 Gas compressers heat the pressurizing medium. After pressurization, vessel pressure may decay as gas temperature equilibrates with ambient conditions.

5.3.3 Emission from flaws is caused by flaw growth and secondary sources (for example, crack surface contact and contained mill scale). Secondary sources can produce emission throughout vessel pressurization.

5.3.4 When pressure within a vessel is low, and gas is the pressurizing medium, flow velocities are relatively high. Flowing gas (turbulence) and impact by entrained particles can produce measurable emission. Considering this, acquisition of AE data may commence at some pressure greater than starting pressure (for example, ⅓ of maximum test pressure).

5.3.5 *Maximum Test Pressure*—Serious flaws usually produce more acoustic emission (that is, more events, events with higher peak amplitude) from secondary sources than from flaw growth. When vessels are pressurized, flaws produce emission at pressures less than normal fill pressure. A maximum test pressure that is 10 % greater than normal fill pressure allows measurement of emission from secondary sources in flaws and from flaw growth.

5.3.6 *Pressurization Schedule*—Pressurization should proceed at rates that do not produce noise from the pressurizing medium and that allow vessel deformation to be in equilibrium with applied load. Pressure holds are not necessary; however, they may be useful for reasons other than measurement of AE.

5.4 Excess background noise may distort AE data or render them useless. Users must be aware of the following common sources of background noise: high gas-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 sand particles, insects, or rain drops. This test method should not be used if background noise cannot be eliminated or controlled.

6. Basis of Application

6.1 *Personnel Qualification*—The 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, 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 Testing 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 *Time of Examination*—The time of examination shall be in accordance with 5.2 unless otherwise specified.

6.4 *Procedures and Techniques*—The procedures and techniques to be used shall be as described in this test method unless otherwise specified. Specific techniques may be specified in the contractual agreement.

6.5 *Extent of Examination*—The extent of examination shall be in accordance with 4.2 and 10.9 unless otherwise specified.

7. Apparatus

7.1 Essential features of the apparatus required for this test method are provided in Fig. 1. Full specifications are in Annex A1.

7.2 Couplant must be used to acoustically connect sensors to the vessel surface. Adhesives that have acceptable acoustic properties, and adhesives used in combination with traditional couplants, are acceptable.

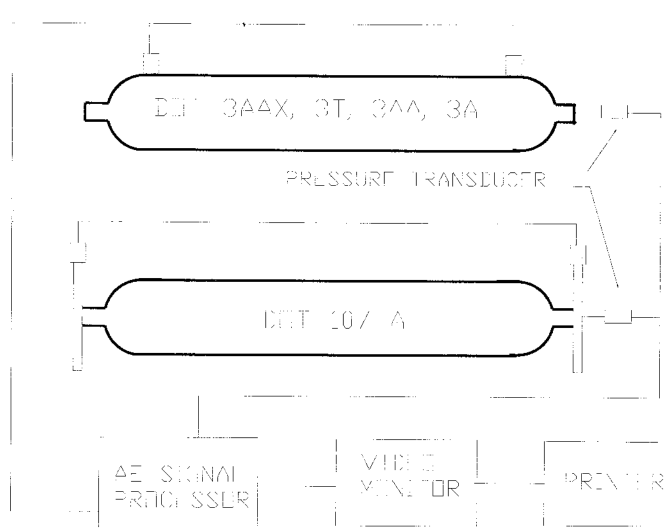

FIG. 1 Essential Features of the Apparatus

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

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

7.5 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 preamp, must not exceed 6 ft (1.83 m).

7.6 Power/signal cable length (that is, cable between preamp and signal processor) shall not exceed 500 ft (152.4 m). See A1.5A1.5.

7.7 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. A printer should be used to provide hard copies of test results.

7.7.1 A video monitor should display processed test data in various formats. Display format may be selected by the equipment operator.

7.7.2 A data storage device, such as a floppy disk, may be used to provide data for replay or for archives.

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

8. Safety Precautions

8.1 As in any pressure test of metal vessels, ambient temperature should not be below the ductile-brittle transition temperature of the pressure vessel construction material.

9. Calibration and Standardization

9.1 Annual calibration and verification of pressure transducer, 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).

9.2 Routine electronic evaluations must be performed any time there is concern about signal processor performance. An AE electronic waveform generator should be used in making evaluations. Each signal processor channel must respond with peak amplitude reading within ±2 dBV of the electronic waveform generator output.

9.3 A system performance check must be conducted immediately before, and immediately after, each examination. A performance check uses a mechanical device to induce stress waves into the vessel wall at a specified distance from each sensor. Induced stress waves stimulate a sensor in the same way as emission from a flaw. Performance checks verify performance of the entire system (including couplant).

9.3.1 The preferred technique for conducting a performance check is a pencil lead break. Lead should be broken on the vessel surface no more than 1.5 in. (3.8 cm) from the sensor. The 2H lead, 0.5-mm diameter, 3-mm long should be used (see Fig. 4 of Guide E 976).

10. Procedure

10.1 Visually examine accessible exterior surfaces of the vessel. Note observations in test report.

10.2 Isolate vessel to prevent contact with other vessels, hardware, and so forth. When the vessel cannot be completely isolated, indicate, in the test report, external sources which could have produced emission.

10.3 Connect fill hose and pressure transducer. Eliminate any leaks at connections.

10.4 Mount an AE sensor at each end of each tube. Use procedures specified in Guide E 650. Sensors must be at the same angular position and should be located at each end of the vessel so that the AE system can determine axial locations of sources in as much of the vessel as possible.

10.5 Adjust signal processor settings. See Appendix X1 for example.

10.6 Perform a system performance check at each sensor (see 9.3). Verify that peak amplitude is greater than a specified value (see Table X1.2). Verify that the AE system displays a correct location (see Note 3) for the mechanical device that is used to produce stress waves (see 9.4 and Table X1.2). Prior to pressurization, verify that there is no background noise above the signal processor threshold setting.

NOTE 3—If desired location accuracy cannot be attained with sensors at two axial locations, then more sensors should be added to reduce sensor spacing.

10.7 Begin pressurizing the vessel. The pressurization rate shall be low enough that flow noise is not recorded.

10.8 Monitor the examination by observing displays that show plots of AE events versus axial location. If unusual response (in the operator's judgment) is observed, interrupt pressurization and conduct an investigation.

10.9 Store all data on mass storage media. Stop the examination when the pressure reaches 110 % of normal fill pressure or 110 % of marked service pressure (whichever is greater). The pressure shall be monitored with an accuracy of ±2 % of the maximum test pressure.

10.9.1 *Examples*:

10.9.1.1 A tube trailer is normally filled to a gage pressure of 2640 psi (18.20 MPa). Pressurization shall stop at 2904 psi (20.02 MPa).

10.9.1.2 A gas cylinder is normally filled to a gage pressure of 613 psi (4.23 MPa). The marked service pressure is 2400 psi (16.55 MPa). Pressurization shall stop at 2640 psi (18.20 MPa).

10.10 Perform a system performance check at each sensor (see 9.3). Verify that peak amplitude is greater than a specified value (see Table X1.2).

10.11 Reduce pressure in vessel to normal fill pressure by bleeding excess gas to a receiver, or vent the vessel.

10.12 Raw AE data should be filtered to eliminate emission from nonstructural sources, for example, electronic noise.

10.13 Replay examination data. Examine the location distribution plots (AE events versus axial location) for all vessels in the examination.

10.14 Based on data replay, determine whether secondary examination (ultrasonic examination) is required. (Ultrasonic examination should be performed in accordance with Practice A 388/A 388M.) Appendix X1 provides examples of such determinations.

11. Report

11.1 Prepare a written report from each test. Report the following information:

11.1.1 Name of the owner of the vessel and the vehicle number (if appropriate).

11.1.2 Test date and location.

11.1.3 Previous test date and previous maximum test pressure. See Note 4.

NOTE 4—If the operator is aware of situations where the vessel was subject to pressures that exceeded normal fill pressure, these should be described in the report.

11.1.4 Any U.S. Department of Transportation (DOT) specification that applies to the vessel.

11.1.5 Any DOT exemption numbers that apply to the vessel.

11.1.6 Normal fill pressure and marked service pressure.

11.1.7 Pressurization medium.

11.1.8 Pressure at which data acquisition commenced.

11.1.9 Maximum test pressure.

11.1.10 Locations of AE sources that exceed acceptance criteria. Location shall include distance from end of vessel that bears the serial number (usually this is stamped in the vessel wall).

11.1.11 Signature of test operator.

11.1.12 Stacking chart that shows relative locations of vessels (if a multiple vessel array is tested).

11.1.13 Visual examination results.

11.1.14 AE test results, including events versus location plots for each vessel and cumulative events versus pressure plot for each vessel.

12. Precision and Bias

12.1 Location accuracy is influenced by factors that affect elastic wave propagation, by sensor coupling, and by signal processor settings.

12.2 It is possible to measure AE and produce AE source locations that cannot be verified by other NDT methods. If such emission are measured, and are produced by flaws, such flaws are small and are not of structural significance.

13. Keywords

13.1 acoustic emission; cylinders; flaws; gas pressure; seamless; steel

ANNEX

(Mandatory Information)

A1. INSTRUMENTATION SPECIFICATIONS

A1.1 Sensors

A1.1.1 The AE sensors shall have high sensitivity within the frequency band of 20 to 1200 kHz. Sensors may be broad band or resonant.

A1.1.2 Sensitivity shall be greater than − 77 dBV (referred to 1 V/µbar, determined by face-to-face ultrasonic test) within the frequency range of intended use.

A1.1.3 Sensitivity within the range of intended use shall not vary more than 3 dB over the intended range of temperatures in which sensors are used.

A1.1.4 Sensors shall be shielded against electromagnetic interference through proper design practice or differential (anticoincidence) element design, or both.

A1.1.5 Sensors shall be electrically isolated from conductive surfaces by means of a shoe (a wear plate).

A1.2 Signal Cable

A1.2.1 The sensor signal cable which connects sensor and preamplifier shall not sensor output more than 3 dB (6 ft (1.83 m) is a typical maximum length). Integral preamplifier sensors meet this requirement. They have inherently short, internal, signal cables.

A1.2.2 Signal cable shall be shielded against electromagnetic interference. Standard coaxial cable is generally adequate.

A1.3 Couplant

A1.3.1 A couplant shall provide adequate ultrasonic coupling efficiency throughout the test.

A1.3.2 The couplant must be temperature stable over the temperature range intended for use.

A1.3.3 Adhesives may be used if they satisfy ultrasonic coupling efficiency and temperature stability requirements.

A1.4 Preamplifier

A1.4.1 The preamplifier shall have noise level no greater than 7 µV rms (referred to a shorted input) within the bandpass range.

A1.4.2 The preamplifier gain shall vary no more than ± 1 dB within the frequency band and temperature range of use.

A1.4.3 The preamplifier shall be shielded from electromagnetic interference.

A1.4.4 The preamplifiers of differential design shall have a minimum of 40-dB common mode rejection.

A1.4.5 The preamplifier shall include a bandpass filter with a minimum of 24-dB/octave signal attenuation above and below the 100 to 300-kHz frequency band.

A1.5 Power/Signal Cable

A1.5.1 The power/signal cables provide power to preamplifiers, and conduct amplified signals to the main processor. These shall be shielded against electromagnetic interference. Signal loss shall be less than 1 dB/100 ft (30.48 m) of cable length. Standard coaxial cable is generally adequate. Signal loss from a power/signal cable shall be no greater than 3 dB.

A1.6 Power Supply

A1.6.1 A stable, grounded, power supply that meets the signal processor manufacturer's specification shall be used.

A1.7 Signal Processor

A1.7.1 The electronic circuitry gain shall be stable within ±2 dB in the temperature range from 40 to 100°F (4.4 to 37.8°C).

A1.7.2 Threshold shall be accurate within ±2 dB.

A1.7.3 Measured AE parameters shall include: threshold crossing counts, peak amplitude, arrival time, rise time, and duration for each hit. Also, vessel internal pressure shall be measured.

A1.7.4 The counter circuit shall count threshold crossings within an accuracy of ±5 % of true counts.

A1.7.5 Peak amplitude shall be accurate within ±2 dBV.

A1.7.6 Arrival time at each channel shall be accurate to within ±1.0 µs.

A1.7.7 Duration shall be accurate to within ±10 µs.

A1.7.8 Threshold shall be accurate to within ±1 dB.

A1.7.9 Arrival time shall be accurate to 0.5 µs.

A1.7.10 Rise time shall be accurate to ±10 µs.

A1.7.11 Parametric voltage readings from pressure transducers shall be accurate to within ±5 % of the marked service pressure.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE INSTRUMENT SETTINGS AND REJECTION CRITERIA

X1.1 A database and rejection criteria are established for some DOT specified vessels. These have been described in the NDT Handbook.[7] More recent criteria are described in this section. Some vessel types, typical dimensions, and service pressures are listed in Table X1.1.

X1.2 Criteria for determining the need for secondary examination were established while working with AE equipment with setup conditions listed in Table X1.2.

X1.3 Need for secondary examination is based on location distribution plots (that is, plots of AE events versus axial location) after AE data acquisition is completed.

X1.3.1 *Cylindrical Portion of Vessel*—The DOT 3AAX and 3T 3AA and 107A tubes are currently retested with this AE test method. For 3AAX and 3T and 3AA tubes, if five or more AE events occur within an 8-in. (20.3-cm) axial distance, on the cylindrical portion of a tube, then that part of the tube must be examined with a secondary NDT method (for example, ultrasonic examination). Any flaw that is detected must be precisely located, and flaw dimensions must be determined.

X1.3.2 *Ends of Vessel*— For DOT 3AAX and 3T and 3AA tubes, if five or more AE events are measured outboard of a sensor, each of these events is detected by both sensors, and the peak amplitude at the "first hit" sensor is 43 dBV or more, then the end of the tube at the "first hit sensor" (that is, the sensor with five or more first hits) must be examined. Any flaw that is detected must be precisely located, and flaw dimensions must be determined using secondary NDT method (for example, ultrasonic examination).

X1.3.3 The DOT 107A tubes are examined with sensors mounted on the end flanges. If five or more AE events occur within 8-in. (20.3-cm) axial distance on the cylindrical portion or end of the tube, then that part of the tube must be examined with a secondary NDT method (for example, ultrasonic examination). Any flaw that is detected must be precisely located, and flaw dimensions must be determined.

X1.4 *Rejection Criterion:*

X1.4.1 Vessels that contain flaws that are large enough to be "fracture critical flaws," or that contain flaws large enough to grow to fracture critical size before another re-examination is performed, shall be removed from service.

X1.4.2 "Fracture critical" flaw dimensions are based upon fracture mechanics analysis of a vessel using strength properties that correspond to materials of construction.

X1.4.3 Analyses of DOT 3AAX and 3T tubes are described by Blackburn and Rana.[8] Fracture critical flaw depths were calculated, and fatigue crack growth (under worst case conditions) was estimated. Flaw depths that could grow to half the fracture critical size were judged too large. They should not remain in service. Based upon this conservative approach, DOT Specification 3AAX and 3T tubes with maximum flaw depths of 0.10 in. (2.54 mm), or more, should be permanently removed from service.

X1.4.3.1 The DOT 3AAX and 3T cylinders have been evaluated by Blackburn and Rana.[8] The maximum allowable flaw depth was calculated to be 0.10 in. (2.54 mm).

X1.4.3.2 The DOT 3AA and 3A cylinders were evaluated

[7] Miller, R. K., and McIntire, P., *Nondestructive Testing Handbook*, 2nd ed., Vol 5, *Acoustic Emission Testing*, American Society for Nondestructive Testing, Colombus, Ohio, 1987, pp. 161–165.

[8] Blackburn, P. R., and Rana, M. D., "Acoustic Emission Testing and Structural Evaluation of Seamless, Steel, Tubes in Compressed Gas Service," *Transactions of the American Society of Mechanical Engineers, Journal of Pressure Vessel Technology*, Vol 108, May 1986, pp. 234–240.

TABLE X1.1 Specified Cylinders, Typical Dimensions, and Service Pressures

Specification	DOT 3AAX	DOT 3T	DOT 3A	DOT 3AA	DOT 107A
Outside diameter, in. (cm)	22 (55)	22 (56)	9.63 (25)	9.63 (25)	18 (46)
Nominal wall thickness, in. (cm)	0.54 (1.37)	0.42 (1.07)	0.31 (0.79)	0.25 (0.64)	0.75 or 0.86 (1.9 or 2.2)
Length, ft (m)	18 to 40 (0.5 to 12)		12 to 32 (4 to 10)		33 (10)
Typical service pressure, psi (MPa)	2400 (16.6)				2600 or 3300 (18 or 23)
Typical fill pressure, psi (MPa)	600 to 3000 (14.14 to 20.68)				2600 to 3300
Alternate retest method	hydrostatic test, at 1.67 times marked service pressure every five years with volumetric expansion measurement				

by Blackburn.[9] Maximum allowable depths were calculated, and 0.06 in. (1.524 mm) was specified for both specifications.

X1.4.3.3 The DOT 107A cylinders have been evaluated by Toughiry.[10] The maximum flaw depth was calculated to be 0.150 in. (3.81 mm).

TABLE X1.2 Acoustic Emission Equipment, Characteristics, and Setup Conditions

Sensor sensitivity	−77 dBV ref. 1V/μbar, at ~150 kHz
Couplant	silicone grease
Preamplifier gain	40 dB (×100)
Preamplifier filter	100 to 300-kHz bandpass
Power/signal cable length	<500 ft (152.4 m)
Signal processor threshold	32 dBV (for example, 1 uV = 0 dBV at preamplifier input)
Signal processor filter	100 to 300-kHz bandpass
Dead time	10 ms
Background noise	<27 dBV (for example, 1 uV = 0 dBV at preamplifier input)
Sensitivity check	>70 dBV (PLB, 0.3 mm, 0.1 in., 4 in.)

[9] Docket No. 11099, Application for Exemption, Appendix II," Maximum Allowable Flaw Depth, 3A and 3AA Tubes," U.S. Department of Transportation, Jan. 14, 1988.

[10] Toughiry, M. M., Docket No. 11059, Application for Exemption from the Requirements of *Hazardous Materials Regulations of the DOT*, U.S. Bureau of Mines, Helium Field Operation, June 1993.