BS 8562:2011

BSI Standards Publication

Gas cylinders – In situ, non-destructive examination and testing of refillable seamless steel tubes of water capacity between 150 L and 3 000 L, used for compressed gases – Specification

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ISBN 978 0 580 73748 0

ICS 23.020.30

The following BSI references relate to the work on this standard:
Committee reference PVE/3
Draft for comment 10/30238376 DC

Publication history
First published March 2011

Amendments issued since publication

Date	Text affected

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Foreword

Publishing information

This British Standard is published by BSI and came into effect on 31 March 2011. It was prepared by Subcommittee PVE/3/7, *Gas containers – Gas cylinder (receptacle) operations*, under the authority of Technical Committee PVE/3, *Gas containers*. A list of organizations represented on this committee can be obtained on request to its secretary.

Information about this document

This British Standard is intended to ensure that seamless steel tubes, that are inaccessible after installation are satisfactorily periodically inspected and tested prior to continued service.

An example of an in situ examination standard is that for Compressed Natural Gas (CNG) cylinders installed on-board automotive vehicles (BS ISO 19078).

The inspection and test programme has to be carried out only by competent persons.

NOTE A competent person has the necessary technical knowledge, experience and authority to assess and approve materials for use with gases and to define any special conditions of use that are necessary. Such a person will normally be formally qualified in an appropriate technical discipline. A competent person has to be impartial and free of any pressures that could influence the independence of their judgement.

Product certification/inspection/testing. Users of this British Standard are advised to consider the desirability of third-party certification/inspection/testing of tubes to check conformity with the requirements of this British Standard, preferably by an authorized inspection body recognized by the competent authority responsible for the application of the tubes being assessed.

Users of this British Standard are advised to use equipment for measurement, testing and examination of tubes in accordance with the requirements of this standard that is maintained and calibrated within a documented quality management system.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is "shall".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Tubes covered by this standard come under the Pressure System Safety Regulations (PSSR) [1, 2], and so need to have a Written Scheme of Examination when used onshore, and under the Offshore Installations (Safety Case) Regulations [3, 4] when used offshore.

Compliance with a British Standard cannot confer immunity from legal obligations.

1 Scope

This British Standard specifies requirements for using a combination of appropriate in situ, Non-Destructive Examination (NDE) techniques [e.g. visual examination, Acoustic emission Testing (AT) and Ultrasonic Examination (UE)] when periodically inspecting and testing tubes of seamless steel construction and water capacity between 150 L and 3 000 L, used for compressed gases for a further period of service.

This British Standard is applicable only to tubes installed in locations where attempting any removal from their containing superstructure would be hazardous or impossible (e.g. offshore oil installations), or where the downtime required to remove the tube would hinder safe operation of a plant or service (e.g. power generation, hospitals, advanced research applications and marine installations such as heave compensation systems on semi-submersible drilling rigs).

Indication of any anomaly in the tube(s) under test that are revealed at the time of in situ inspection have to be evaluated using a different technique to be able to quantify (location and frequency) and size any possible imperfection.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 473, *Non-destructive testing – Qualification and certification of NDT personnel – General principles*

BS EN 1968:2002, *Transportable gas cylinders – Periodic inspection and testing of seamless steel gas cylinders*

BS EN ISO 13769, *Gas cylinders – Stamp marking*

BS EN ISO 16148, *Gas cylinders – Refillable seamless steel gas cylinders – Acoustic emission testing (AT) for periodic inspection*

BS ISO 25760, *Gas cylinders – Operational procedures for the safe removal of valves from gas cylinders*

ISO 6406:2005, *Gas cylinders – Seamless steel gas cylinders – Periodic inspection and testing*

3 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1 acoustic emission (AE) activity

number of bursts (or events if the appropriate conditions are fulfilled) detected during a test or part test

3.2 flow noise

acoustic emission events caused by the action of pressurizing the vessel and not by any structural flaws within it

NOTE This can be reduced by slowing the fill rate and/or filtering out such emissions electronically within the AE recording equipment.

3.3 total test pressure
pressure that is 110% of the working pressure

3.4 working pressure
settled pressure of a compressed gas at a uniform reference temperature of 15 °C in a full gas cylinder.

NOTE See ISO 10286.

4 Operational principles

4.1 General

The periodic inspection and test shall comprise a pre-inspection site visit followed by an on-site inspection.

The maximum time interval for the periodic inspection shall be as stipulated in P200 of the current version of the ADR [5] (in force at the time of the inspection) for the gas concerned. Where other organizations/institutions stipulate a shorter time interval, this shall be complied with. The applicable time interval shall be included in the written scheme of examination.

At all times the safety of all personnel in the vicinity of the installation shall be taken into account.

NOTE 1 The techniques used to evaluate the tube condition within the installation may include:

a) hydraulic pressure testing;

b) acoustic emission testing;

c) internal and external visual examination;

d) ultrasonic thickness survey;

e) ultrasonic flaw detection;

f) magnetic particle inspection;

g) dye penetrant inspection;

h) radiography;

i) eddy current inspection;

j) hardness testing.

NOTE 2 At the discretion of the competent person other appropriate test techniques may be used.

4.2 Pre-inspection site visit

Prior to any tests taking place, a pre-inspection visit to the site of the tube installation shall be undertaken to gather all the necessary information to ensure that an appropriate set of tests are performed for the installation and the suitability of the tube to be examined in situ.

To ensure that the installation itself and any areas of concern related to it are understood, the site owner/operator shall be asked to complete a questionnaire before the pre-inspection visit. The pre-inspection visit shall, as a minimum, identify and record:

a) the application of the tube to be examined/tested (e.g. submersible, a static storage service (off shore or on shore), used in a diving application);

b) the manufacturing standard/specification of the tube to be examined;

c) details of the tube installation including at least:

   1) the feasibility of conducting an in situ test at the desired location;

   2) a listing of any regulations that apply to the installation;

   3) a location-based risk analysis;

   4) the nature of the gas contained;

   5) the pressure rating of the tube(s) to be examined;

   6) the pipework configuration, and its pressure rating, leading to and from the tube;

   7) the type of any valve, pressure control device, ancillary item (e.g. pressure gauge) and their pressure ratings fitted to the tube or its pipework;

   8) the ability of the tube(s) to be inspected to withstand the total test pressure; and

   9) the environmental conditions at the test site (e.g. noise and vibration levels).

4.3 On-site inspection

4.3.1 General

Having gathered and analysed the data from the pre-inspection site visit (see **4.2**), the most suitable test method(s) for the particular tube installation under consideration shall be selected.

At all times the inspection work shall be carried out in accordance with the appropriate written procedures(s) for the test(s) to be performed.

Periodic inspection and testing shall comprise as a minimum:

a) a visual examination (see **4.3.2**) of all accessible external surfaces, internal surfaces and an acoustic emission test (see **4.3.3**) coupled with any other tests deemed necessary (see **4.3.5**); or

b) a visual examination (see **4.3.2**) of all accessible external surfaces, internal surfaces and a hydraulic test (see **4.3.4**) coupled with any other tests deemed necessary (see **4.3.5**).

If it is found that the tube surface coating is unsatisfactory for a further period of use, it shall be brought to the attention of the tube owner.

If at any stage of the inspection process the valve/plug/adaptor/pressure control device within the tube needs to be removed, this shall be done in accordance with the requirements of BS ISO 25760.

4.3.2 Visual examination

All external visual examinations (see Annex A) shall be performed in accordance with the requirements of ISO 6406:2005, Annex B.

All internal visual examinations shall be performed in accordance with the requirements of BS EN 1968:2002.

All signs of corrosion and any form of mechanical damage shall be carefully investigated.

Where necessary, additional equipment (e.g. a video camera or an endoscope) shall be used to help clarify and interpret the initial observations.

4.3.3 Acoustic emission testing

Acoustic emission testing (AT) shall be carried out in accordance with the requirements of BS EN ISO 16148 (an examination procedure using AT is described in Annex B).

4.3.4 Hydraulic testing

Hydraulic testing shall be carried out in accordance with the requirements of ISO 6406:2005, Clause **11**.

4.3.5 Supplementary tests

Where there is doubt about the type and/or severity of any imperfection identified by the tests in **4.3.2** to **4.3.4**, additional test(s) shall be conducted to supplement or clarify the results obtained [e.g. ultrasonic examination (UE), magnetic particle inspection, dye penetrant inspection, radiography, eddy current inspection, hardness testing].

Where particular parts of the tube are inspected using UE, the relevant requirements of ISO 6406:2005, **11.4** shall be met. Corrosion mapping or flaw detection may be used to further evaluate imperfection distribution.

NOTE 1 Corrosion mapping is a pulse-echo ultrasonic technique that produces a colour graphic image of the area scanned. It involves scanning with one or more straight beam probes using a prescribed, dual axis scan pattern over the tube surface whilst taking thickness measurements. The measurements are converted into digital values, which are colour-coded to create a topographic map of the tube wall thickness profile. Images (C-scans) from individual scan areas can be assembled together to create a composite image covering large areas of the tube surface. The thickness profile of the corroded area can be evaluated at the time of the test and/or can be stored and used to monitor future surface degradation.

NOTE 2 Eddy current testing may be used as part of the overall programme for tube examination and verification. The requirements for the examination, verification and equipment used for this technique are specified in BS EN ISO 15548.

NOTE 3 Magnetic particle inspection (MPI) may be used as part of the overall programme for the evaluation and detection of surface breaking and slightly sub-surface discontinuities within the tube. The general principles for this technique are given in BS EN ISO 9934-1.

5 NDE personnel qualification

All personnel performing NDE work shall be certified in accordance with relevant standards (e.g. BS EN 473).

6 Marking

After satisfactory completion of the periodic inspection and test programme the shoulder of the tube, where accessible, shall be stamp-marked with the test details in accordance with the requirements of BS EN ISO 13769. The marking shall include the date of the next retest (YYYY).

Under no circumstances shall the parallel section of the tube be hard-stamped.

Where the tube shoulder cannot be stamped, the nearest position to it where damage is unlikely to occur or the information unlikely to be rendered illegible shall be stamped. Where it is not possible to stamp the tube, other techniques shall be used to mark the information (e.g. installing a data plate or paint stencilling) or the information may be presented on another integral part of the installation, but as close as possible to the tube shoulder.

7 Certification/Report

For every tube examined a test certificate/report shall be issued and signed by the competent person giving the following information as a minimum:

a) the serial number(s) of the tube(s) examined;

b) a description of the installation (e.g. site details, tube installation and its/their position within the site);

c) the test date (day/month/year);

d) details of all tests performed and their outcomes;

e) a listing of all standards and parameters used during the course of the tests/examinations (e.g. pressures applied, equipment used);

f) a listing of any deviations from the test/examination protocols used;

g) a listing of any deviations that have been identified but not deemed sufficient for the tube to fail the test; and

h) the date of next test (the elapsed period between tests may be shortened if any deviations are observed during the course of the test programme).

8 Rendering tubes unserviceable

NOTE The decision to reject a tube may be taken at any stage during the periodic inspection and test procedure.

If it is not possible to recover a rejected tube, it shall, after notifying the owner, be made unserviceable for holding gas under pressure so that it is impossible for any part of the tube, especially the shoulder, to be re-issued into service.

Once a tube has been rejected and after ensuring it is empty and free of gas, it shall be rendered unserviceable by, for example:

a) crushing (preferably in the shoulder area);

b) burning an irregular hole in the top dome equivalent in area to approximately 10% of its area or, in the case of a thin-walled tube, piercing it in at least three places;

c) cutting the neck in an irregular fashion;

d) cutting it, including the shoulder, into two or more irregular pieces;

e) bursting it in a safe manner.

Annex A (informative) Description, evaluation of defects and conditions for rejection of refillable seamless steel tubes at the time of visual inspection

A.1 General

Defects can be physical, material or due to corrosion (e.g. as a result of environmental or service conditions to which the tube has been subjected during its life). This annex gives general guidelines regarding the application of rejection criteria.

Due to the nature of the examinations performed, it might not be always possible to see all the stamp markings.

Defects in the form of a sharp notch may be repaired using an approved method (e.g. grinding or machining). After any repair using a metal removal technique, the tube wall thickness should be checked (e.g. ultrasonically). The remaining wall thickness should be at least equal to the minimum guaranteed wall thickness.

A.2 Physical or material defects

The types of defect included in this category include but are not limited to:

a) dents;

b) cut or gouges;

c) cracks;

d) fire damage;

e) arc or torch burns; and

f) suspicious marks.

Evaluation of physical or material defects should be in accordance with the requirements of ISO 6406:2005.

Attachments (e.g. foot-rings/supports) should be inspected to ensure they are suitable for their intended purpose.

A.3 Corrosion

A.3.1 General

Tubes can be subjected to environmental conditions that could cause external corrosion and in-service conditions that could result in internal corrosion. There is difficulty in presenting definite rejection limits in tabular form for all sizes and types of tube and their service conditions. Rejection limits are usually established as a result of considerable field experience.

Extensive experience and judgment are required in evaluating whether tubes that have corroded internally are safe and suitable for return to service. Where necessary, it is important that the tube internal surface is cleaned of corrosion products prior to inspection.

A.3.2 Corrosion types

Typical types of corrosion are:

a) general;

b) local;

c) chain pitting or line;

d) isolated pits or crevices.

A.3.3 Rejection criteria

For all rejection criteria see ISO 6406:2005, Annex B.

Annex B (informative) Procedure for the examination of refillable seamless steel tubes using acoustic emission (AE) techniques

B.1 General

This procedure relates to the AE examination of refillable seamless steel tubes used for the storage of compressed gases and is based on the requirements of BS EN ISO 16148.

The procedure involves pressurizing the vessel to a level greater than that experienced during the previous 12 months of service. The overpressure is normally 10% above the tube working pressure and is intended to overcome the Kaiser effect.

This procedure is not to be used at tube temperatures below 5 °C. Below this temperature the tube can become more brittle and there is less acoustic emission before failure.

The AE examination is used to detect and locate the longitudinal position of defects for subsequent examination using other NDT methods [e.g. shear wave ultrasonics to size (depth) defects and to determine their circumferential position].

B.2 Equipment

The equipment to be used is shown in Figure B.1.

B.3 Safety

All equipment used to conduct the tests should be declared safe for use at the test site before any testing begins.

Some critical factors which might need to be considered are:

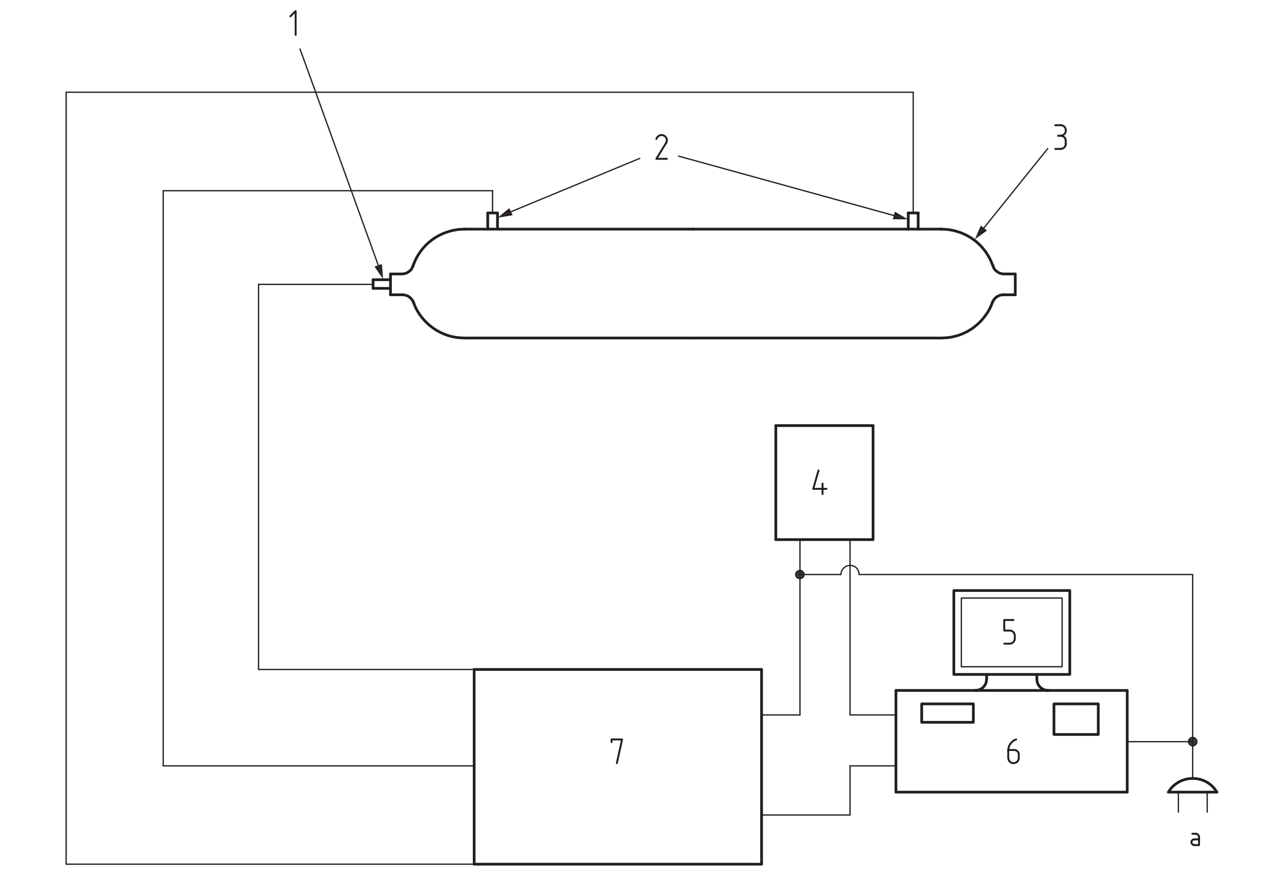
a) the suitability of the pressurization equipment to be used;

b) whether potentially explosive environments (e.g. hydrogen tubes) are present;

c) whether any circumstances which could result in tube failure (e.g. prior usage, history and consequences) are present;

d) the electrical safety (e.g. portable appliance testing (PAT), stability of the electricity supply and its absolute voltage) of the power supply and test equipment to be used.

Figure B.1 **Example of AE examination equipment diagram and sensor placing**



Key

1 Pressure transducer

2 Acoustic emission sensors with integral preamplifier (two for each tube)

3 Tube with sensors mounted on sidewall

4 Printer

5 Video monitor

6 Computer

7 Acoustic emission signal processor power

B.4 Method

B.4.1 General

Tubes are generally tested in banks of up to 12 (24 channels/sensors).

The traceability of each tube/sensor/channel should be retained.

B.4.2 Procedure

B.4.2.1 Ensure that where the sensors are to be attached, the surface of the tube is clean and free from grease and loose material. It might be necessary to prepare the tube surface before attaching the sensor or couplant to ensure a good acoustic contact (e.g. by removing excess paint or surface corrosion).

B.4.2.2 Attach two sensors to each tube, one as near to each of the domed ends as possible (usually on the parallel section just before the dome radius begins). Attach sensors to each tube in similar locations (in order to obtain comparable readings) using a suitable acoustic couplant. There should be no air gaps between the sensor and tube(s) after installation.

B.4.2.3 Calibrate and check system performance by performing five pencil lead break tests (using a H-N 0.5 pencil with a 3 mm extension) per sensor. Each pencil lead break test should be performed 50 mm from the sensor along the parallel part of the tube.

Each individual pencil break should produce, at the sensor, a minimum peak amplitude of 70 dB. Results should be recorded for each individual sensor and an average peak amplitude value (P_B) calculated for each.

If the output from a sensor gives a peak amplitude that deviates by more than P_B ±4 dB, re-mount the sensor and repeat the pencil lead break test. If, after re-mounting the sensor, output remains outside limits, replace it with a new sensor and repeat **B.4.2.1** and **B.4.2.2**.

B.4.2.4 Pressurize the tube to 50% of the total test pressure to be applied and hold for 10 min. Perform a background acoustic noise check by monitoring the output from the sensors in order to evaluate whether there is any noise present from a combination of external sources (e.g. rain, wind, foliage brushing against the tube).

If background noise is present, the source should be established and eliminated, or its effect allowed for in the test results.

B.4.2.5 Continue to pressurize the tube using a fill rate slow enough to avoid excessive flow noise (e.g. 40 bar/h) until the maximum test pressure has been achieved.

B.4.2.6 Once the test sequence has been started, it may be held at the AE operator’s discretion at any point within the test cycle. Hold points are not mandatory.

B.4.2.7 Monitor and record (e.g. using a mass storage device) all sensor outputs during the test. If the data indicate that there are five or more anomalies in the tube within a linear distance of 200 mm, identify the area for further investigation by a different NDT method.

B.4.2.8 When the maximum test pressure is reached, repeat step **B.4.2.3** to confirm system functionality.

B.5 Real-time evaluation criteria

The real-time criteria that will result in a stop (e.g. for rejection of the tube) or pause (e.g. for further data analysis) in the pressurization sequence should be clearly defined before testing begins.

Supporting data for the choice of evaluation criteria should be made available from an appropriate source (e.g. database, standard or experience). Depending upon the location of the test site, rejection criteria can vary where specific local regulations apply.

Criteria that will result in rejection of the tested tube or in a stop of the pressurization sequence for further inspection are influenced by factors such as:

a) tube type;

b) tube material and heat treatment;

c) first or subsequent pressurization.

Tubes that have been rejected based on AE data should undergo a second inspection of the defective area(s) using an alternative test method (e.g. UE) before a decision is made about their being returned to service.

Real-time evaluation criteria may be based on events such as:

1) an increase in AE activity and/or energy as a function of tube pressure;
2) number N_1 of located burst signals with a distance-corrected peak amplitude above a high specific value A_1;
3) number N_2 of located burst signals with a distance-corrected peak amplitude above a low specific value A_2 within an interval of size X % of the maximum distance between sensors.

NOTE The value of X depends on the AE equipment used, the number of sensors and the size of the tube (e.g. diameter size).

Tube pressurization should be stopped immediately if the AE energy increases in incremental steps from a defined value, for example:

i) the AE energy doubles in two consecutive pressure intervals of 5% of the maximum test pressure; or
ii) one of the specific predefined values for either N_1 or N_2 is exceeded.

B.6 Test report

Once all testing is completed, a test report from each AE examination should be prepared, containing:

a) name(s) of tube owner(s);
b) tube serial number(s) and manufacturer(s);
c) test date and location;
d) any previous examination date(s) and test pressure(s);

NOTE If the operator is aware of situations where the tube was subjected to pressure that exceeded normal filling pressure, these should be described in the report.

e) normal filling pressure (supplied by the tube owner) and marked working pressure;
f) pressurization medium;
g) pressurization rate;
h) pressure at which data acquisition commenced;
i) AE test pressure;
j) AE sensors location(s);
k) location of AE sources that exceed acceptance criteria, including distance from end of the tube that bears the serial number (usually this is stamped on the tube);
l) any acceptable variation from the AE test procedure;
m) name, qualification and signature of the competent person;
n) stacking chart that shows the relative locations of tubes and, if appropriate, the associated data channel number;
o) external visual exam results;

p) AE examination results including:
   1) events versus location plot for each tube;
   2) distance-corrected amplitudes versus location plot for each tube;
   3) cumulative events versus pressure (or time) for each channel of each tube; and
   4) cumulative energy versus pressure plot for each channel of each tube or energy distribution histograms for each channel;

q) examination procedure and revision number;

r) type of AE instrumentation used;

s) description of the pressure equipment;

t) sketch with dimensions showing sensor and simulated source locations;

u) results of system verifications including documentation; and

v) achieved location accuracy.

Bibliography

Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN ISO 9934-1, *Non-destructive testing – Magnetic particle testing*

BS EN ISO 10286, *Gas cylinders – Terminology*

BS EN ISO 11120, *Gas cylinders – Refillable seamless steel tubes for compressed gas transport, of water capacity between 150 l and 3000 l – Design, construction and testing*

BS EN ISO 15548, *Non-destructive testing – Equipment for eddy current examination*

BS ISO 19078, *Gas cylinders – Inspection of the cylinder installation, and requalification of high pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles*

ISO 9712, *Non-destructive testing – Qualification and certification of personnel*

Other publications

[1] GREAT BRITAIN. The Pressure Systems Safety Regulations 2000, SI 128. London, TSO

[2] NORTHERN IRELAND. Pressure Systems Safety Regulations (Northern Ireland) 2004, SR 222. London, TSO

[3] GREAT BRITAIN. The Offshore Installations (Safety Case) Regulations 2005, SI 3117. London, TSO

[4] NORTHERN IRELAND. The Offshore Installations (Safety Case) Regulations (Northern Ireland) 2007, SR 247. London, TSO

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Further reading

SNT-TC-IA, Recommended practice for non-destructive testing personnel qualification and certification

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