
**Determination of the resistance
to cryogenic spillage of insulation
materials —**

**Part 3:
Jet release**

*Détermination de la résistance des matériaux d'isolation thermique
suite à un refroidissement cryogénique —*

Partie 3: Émission sous forme de jet



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 9, *Liquefied natural gas installations and equipment*.

A list of all parts in the ISO 20088 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The test is intended to be, as far as practicable, representative of a potential accidental pressurized release of cryogenic liquid natural gas (LNG) manufactured in industrial plants. The test includes:

- a) an initial enhanced cooling effect due to the momentum driven liquid contact with the substrate;
- b) a localized force that may be expected in a cryogenic jet release.

This test is designed to give an indication of how cryogenic spill protection systems will perform when subjected to a sudden cryogenic jet release.

The dimensions of the test specimen might be smaller than typical items of structure and plant. The liquid cryogenic jet mass flow rates can be substantially less than that which might occur in a credible event. However, the thermal and mechanical loads imparted to the cryogenic spill protection systems from the cryogenic jet release, described in this document, are representative of a cryogenic LNG jet release with hole size 20 mm or less and release pressure less than or equal to 6 barg.

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Determination of the resistance to cryogenic spillage of insulation materials —

Part 3: Jet release

CAUTION — The attention of all persons concerned with managing and carrying out cryogenic spill tests is drawn to the fact that liquid nitrogen testing can be hazardous and that there is a danger of condensing liquid oxygen (fire/explosion), receiving a ‘cold burn’ and/or the possibility that harmful gases (risk of anoxia) can be evolved during the test. Mechanical and operational hazards can also arise during the construction of the test elements or structures, their testing and disposal of test residues. An assessment of all potential hazards and risks to health shall be made and safety precautions identified and provided. Appropriate training and Personal Protection Equipment shall be given to relevant personnel. The test laboratory is responsible for conducting an appropriate risk assessment in order to consider the impact of liquid and gaseous nitrogen exposure to equipment, personnel and the environment.

1 Scope

This document describes a method for determining the resistance of a cryogenic spill protection (CSP) system to a cryogenic jet as a result of a pressurized release which does not result in immersion conditions. It is applicable where CSP systems are installed on carbon steel and will be in contact with cryogenic fluids.

A cryogenic jet can be formed upon release from process equipment operating at pressure (e.g. some liquefaction processes utilize 40 to 60 bar operating pressure). Due to high pressure discharge, the cryogenic spillage protection can be compromised by the large momentum combined with extreme cryogenic temperature.

Although the test uses liquid nitrogen as the cryogenic liquid, the test described in this document is representative of a release of LNG, through a 20 mm orifice or less, at a release pressure of 6 barg or less, based upon simulated parameters 1 m from the release point. Confidence in this test being representative is based upon a comparison of the expected dynamic pressure of the simulated release in comparison with dynamic pressure from releases in accordance with this document.

It is not practical in this test to cover the whole range of cryogenic process conditions found in real plant conditions; in particular the test does not cover high pressure cryogenic jet releases that might be found in refrigeration circuits and in LNG streams immediately post-liquefaction.

Liquid nitrogen is used as the cryogenic medium due to the ability to safely handle the material at the pressures described in this document. The test condition is run at nominally 8 barg pressure.

ISO 20088-1 covers cryogenic release scenarios which can lead to pooling conditions for steel work protected by cryogenic spill protection as a result of a jet release or low pressure release of LNG or liquid nitrogen. ISO 20088-2 covers vapour phase exposure conditions as a result of a jet release or low pressure release of LNG or liquid nitrogen.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

cryogenic jet release

unintended exposure to cryogenic liquid as a result of a pressurized release

3.2

cryogenic spill protection

CSP

coating or cladding arrangement, or free-standing system which, in the event of a cryogenic jet release, will provide insulation to restrict the heat transfer rate from the substrate

3.3

limiting temperature

minimum temperature that the equipment, assembly or structure to be protected may be allowed to reach

3.4

nozzle

assembly from which the cryogenic liquid is released as a jet

3.5

sponsor

person or organization that requests a test

3.6

specimen owner

person or company that holds/produces a material to test

4 Test configurations

4.1 General

The configuration under which the test is conducted is where the specimen is placed horizontally at height on suitable supports. The test piece is impacted at the mid-point by a horizontal liquid nitrogen cryogenic jet release. Due to safety concerns, it is proposed that the test should only be performed outside, unless there are sufficient safeguards implemented to mitigate the confined space and liquid nitrogen safety risks.

5 Construction of the test apparatus and substrates

5.1 General

The key items required for the test are:

- a nozzle and cryogenic liquid feeder assembly where the temperature and pressure of the liquid can be measured at the point the liquid enters the reducing diameter pipe to the nozzle;
- liquid nitrogen of sufficient volume for the test duration supplied from a tanker capable of offload via a pump to generate the required stable pressure at the nozzle;
- a carbon steel specimen protected with CSP;

- thermocouples to determine the temperature as a function of time in the steel specimen.

5.2 Material

The steel grade used for the test is to be recorded. Where welded plate girders are used, construction is to be representative of the as-built structure. All dimensions are in millimetres and, unless otherwise stated, the following tolerances shall be used:

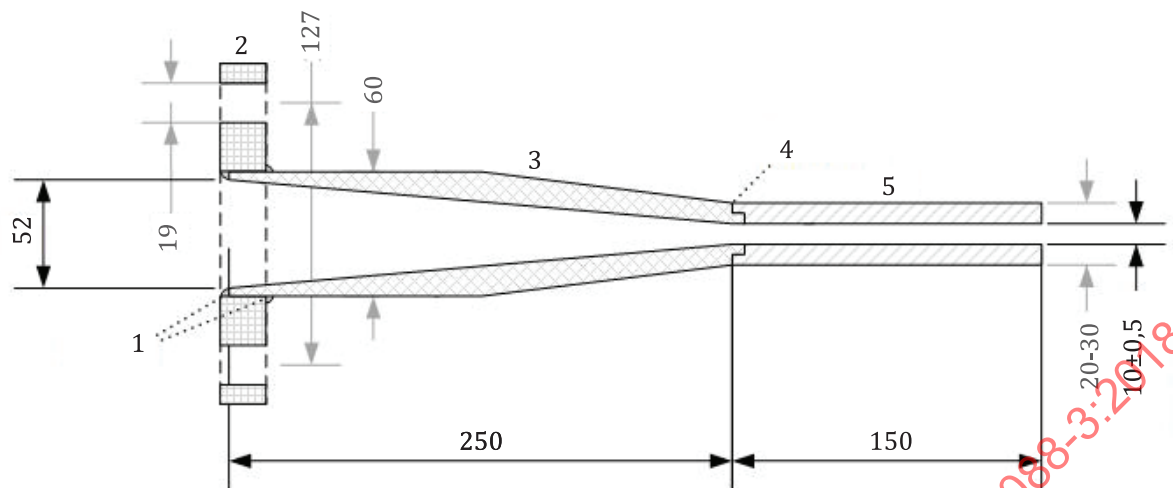
- whole number $\pm 1,0$ mm;
- decimal to point ,0 $\pm 0,4$ mm;
- decimal to point ,00 $\pm 0,02$ mm;
- angles $\pm 0' 30''$;
- radius $\pm 0,4$ mm.

Test specimens shall include as a minimum a beam of designation 406 mm $\times$ 178 mm $\times$ 60 kg/m or tubular specimen of wall thickness 6,3 mm and outer diameter between 270 mm and 350 mm (including the cryogenic spill protection material). All test specimens are to be 2,5 m in length unless otherwise agreed by the sponsor.

5.3 Release nozzle

5.3.1 Nozzle construction

Liquid nitrogen is released towards the specimen from a nozzle as shown in [Figure 1](#). The nozzle shall be of length $(150 \pm 1,0)$ mm, constructed from 10 mm nominal diameter stainless steel pipe with outside diameter of 20 mm to 30 mm, $-0,5/+0,5$ mm giving a wall thickness between 5 mm and 10 mm. The nozzle shall not be tapered and the end shall be clean cut with no chamfering of pipe walls. The nozzle is fed with liquid nitrogen from a 52,5 mm diameter schedule 40 stainless steel pipe gradually reducing in internal diameter to 10 mm over a length of 200 mm to 250 mm.

**Key**

- 1 welds
- 2 slip-on flange
- 3 reducing section
- 4 butt weld
- 5 straight-sided nozzle

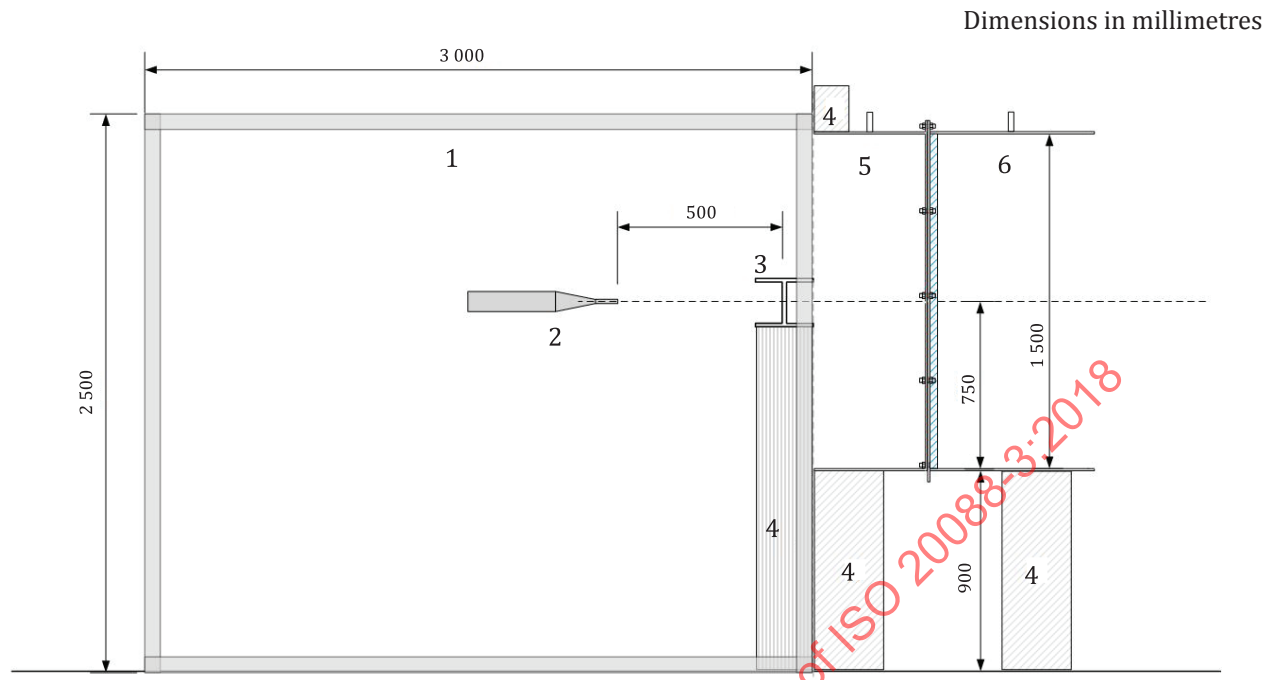
Figure 1 — Feed pipe and nozzle construction with a nozzle of 10 mm wall thickness

5.3.2 Nozzle position

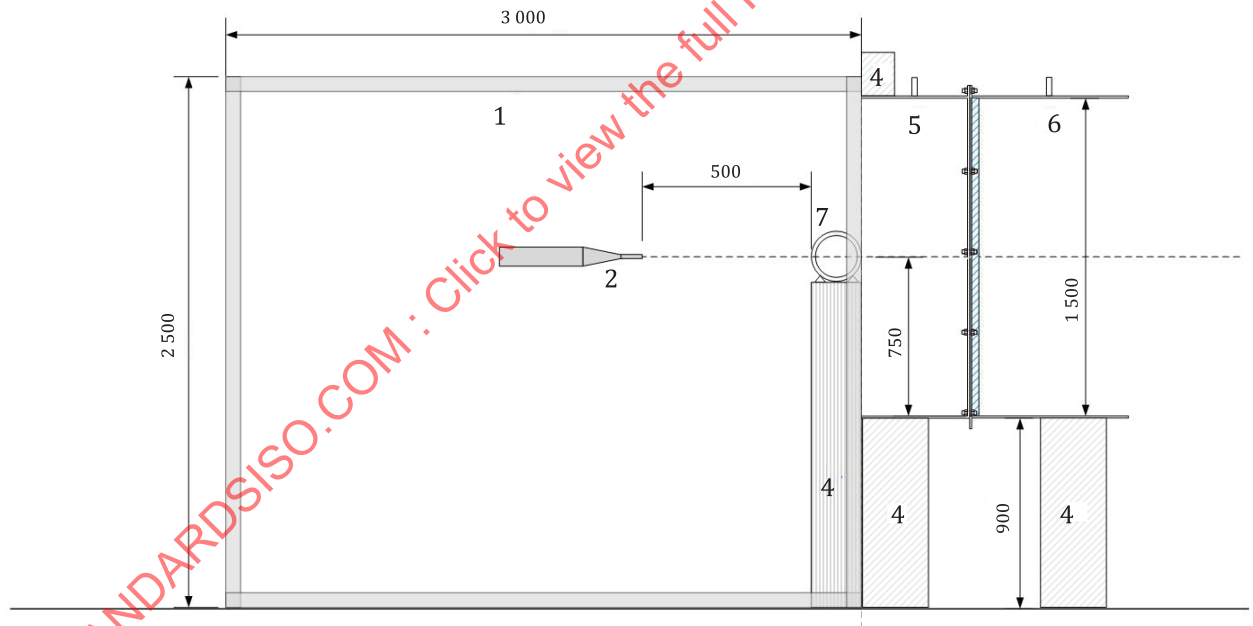
The nozzle shall be positioned horizontally in front of the test specimen, focussed at the centre point such that the cryogenic jet release impacts normal to the web of the beam [dry film thickness (DFT) measurement point 7] or normal to a tangent drawn where the radius of the tube intersects the centre point of the tubular (DFT measurement point 3) as shown in [Figure 4](#). The tip of the nozzle shall be located (500 ± 10) mm from the protected surface of the test specimen as shown in [Figure 2](#).

5.4 Specimen support

A generic support shall be used to hold and support the test specimen. The support shall be fabricated from a material resistant to cryogenic temperatures. It is the responsibility of the test laboratory to ensure proper design of such an item and to ensure that pool formation of cryogenic liquid cannot occur and come in contact with the sample (for tubular specimens, no liquid should be allowed to enter the inside of the specimen). An example is given in [Figure 2](#) with more detailed figures showing the overall test configuration in [Annex B](#).



a) Beam configuration (side view — including environmental chamber)



b) Pipe configuration (side view — including environmental chamber)

Key

- 1 environmental chamber
- 2 release nozzle ($8 \pm 0,8$) barg (average pressure $\pm$ standard deviation)
- 3 specimen (beam shown)
- 4 specimen (and recirculation and protective chambers) supports
- 5 recirculation chamber (insulated on back surface)
- 6 protective chamber (support and stability)
- 7 specimen (tubular shown)

Figure 2 — Example of specimen support and side view configuration

5.5 Recirculation chamber

A recirculation chamber as shown in [Figure 3](#) shall be placed behind the specimen to provide the means to standardize the atmospheric test environment. Insulation board (U Value maximum 1,25 W/m².K) is to be affixed to the rear of the recirculation chamber. To provide extra support and stability, a steel box is to be attached to the rear of the recirculation chamber as shown in [Figure 2](#) (refer to ISO 22899-1).

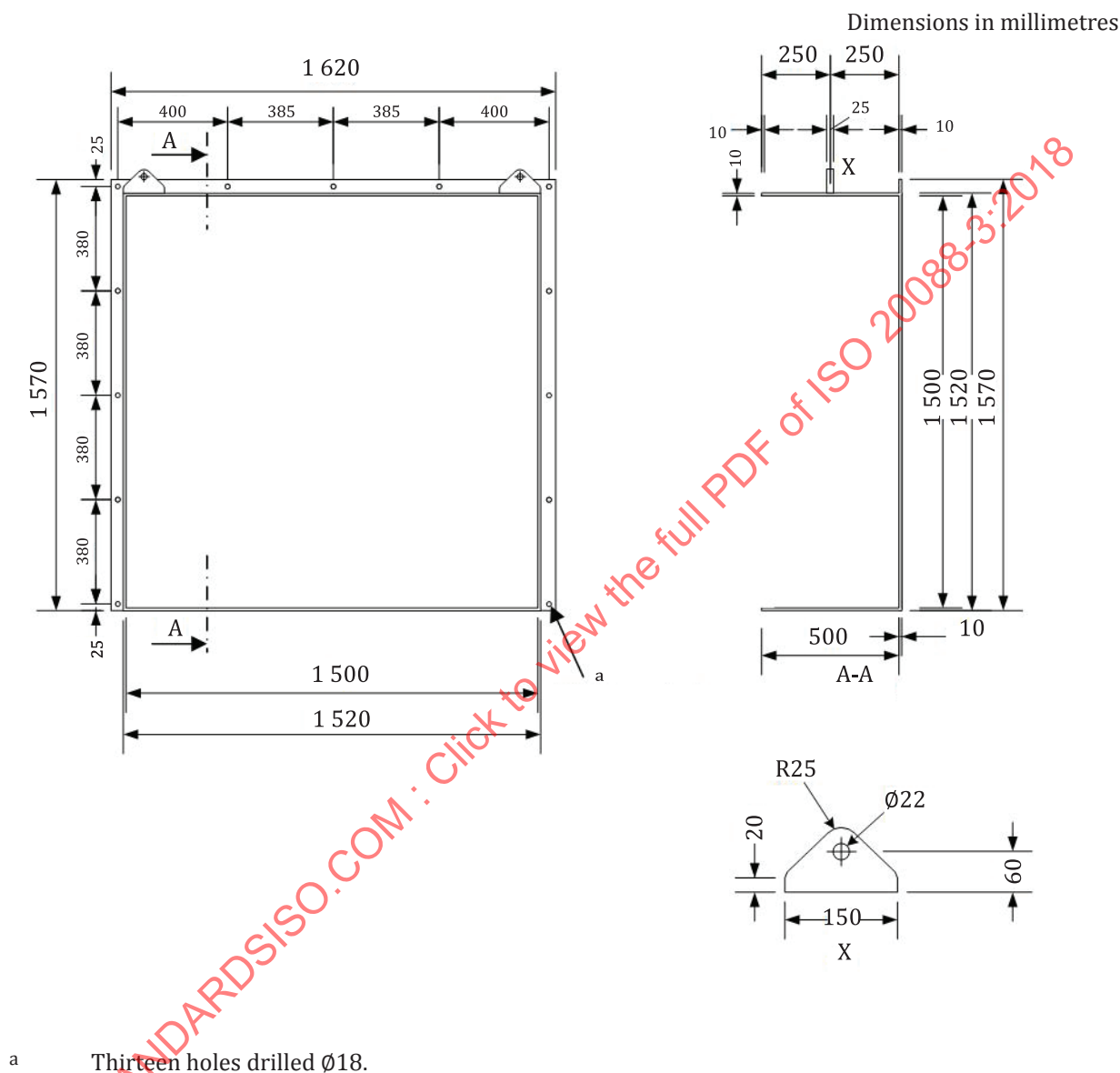


Figure 3 — Recirculation chamber

6 Cryogenic spill protection materials

6.1 General

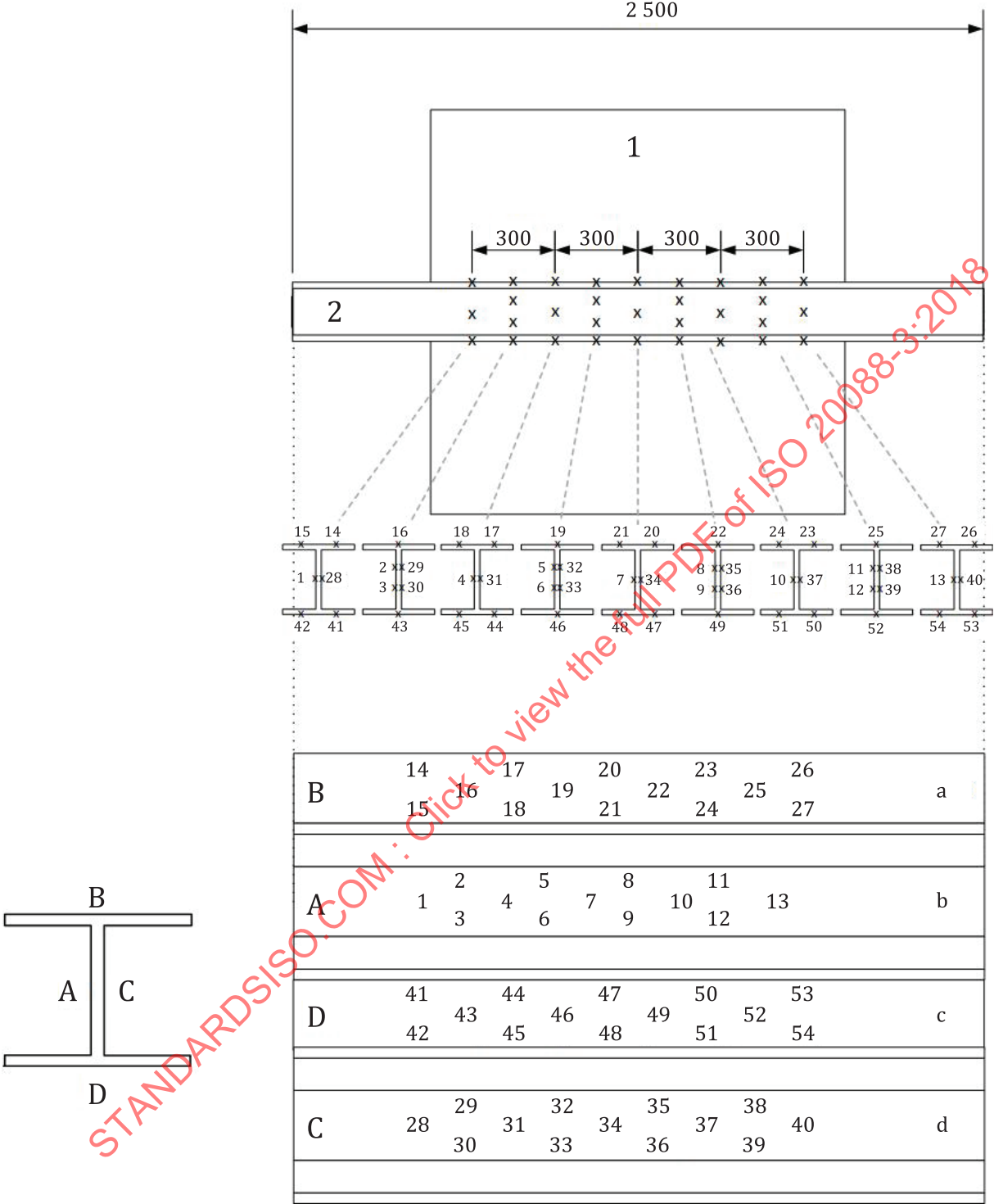
CSP systems generally come in two forms; wet applied materials/coatings and preformed systems. Preformed systems include boards, tiles, blankets, sandwich panels, etc., and are characterized by systems that include joints and fixings. Preformed systems may be used in conjunction with wet applied materials.

The application/installation methodology, including any necessary surface preparation, reinforcement, thickness, top-coats, field joints, etc., is to be determined by the sponsor and/or specimen owner and details provided for inclusion within the test report.

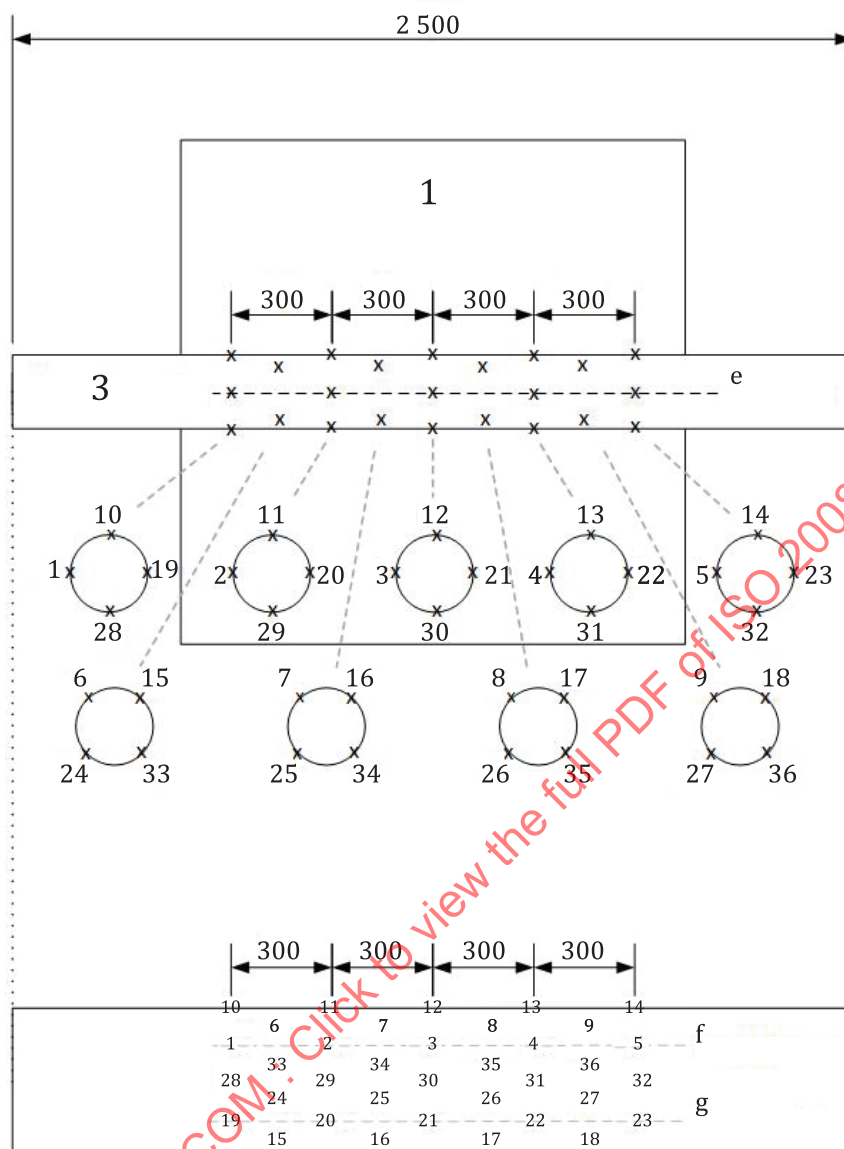
The thickness for sprayed applied systems shall be measured as close as practicable to the positions identified in [Figure 4](#), avoiding readings directly over thermocouples wires which may give false readings. For preformed systems, thicknesses shall be measured for the system components at locations on the specimen corresponding to those shown in [Figure 4](#). If there are clear signs of thinning or thickening at positions away from those indicated for measurement, additional measurements should be taken and reported.

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Dimensions in millimetres



a) Beam DFT measurement locations



b) Tubular DFT measurement locations

Key

- 1 recirculation chamber
- 2 beam sample
- 3 pipe sample
- a Top.
- b Exposed face.
- c Bottom.
- d Unexposed face.
- e Centre line.
- f Exposed face centre line.
- g Unexposed face centre line.

Figure 4 — Thickness measurement points for I section testing and hollow section testing

6.2 Wet applied coating systems

For CSP systems/materials that are wet applied as coatings, the CSP systems/materials should be applied in the same manner as will be used in service.

6.3 Preformed system testing

For preformed systems, the system shall also be installed in the same manner as will be used in service.

The method of installing the system shall include representative joints, fixings and wet applied material interface details. A minimum of two joints should be included as follows:

- 1) one joint located over thermocouples: 11-17 (I section) 9-12 (pipe) as shown in [Figure 5](#);
- 2) one or two joints located over thermocouples: 3, 8, 14, 20, 25 (I section) 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 (pipe) as shown in [Figure 5](#). Where one joint is used this shall be directly exposed to the cryogenic jet.

Joints should be tested, either in a single test or separate tests as determined by the sponsor and/or specimen owner, ensuring the details are representative in accordance with [Clause 10](#).

7 Instrumentation for test specimens

7.1 General

Thermocouples shall be fastened to all test specimens. The type and fixing shall be in accordance with one of the methods described in [Annex A](#).

Readings shall be recorded at intervals of not more than 1 s.

7.2 Thermocouple location

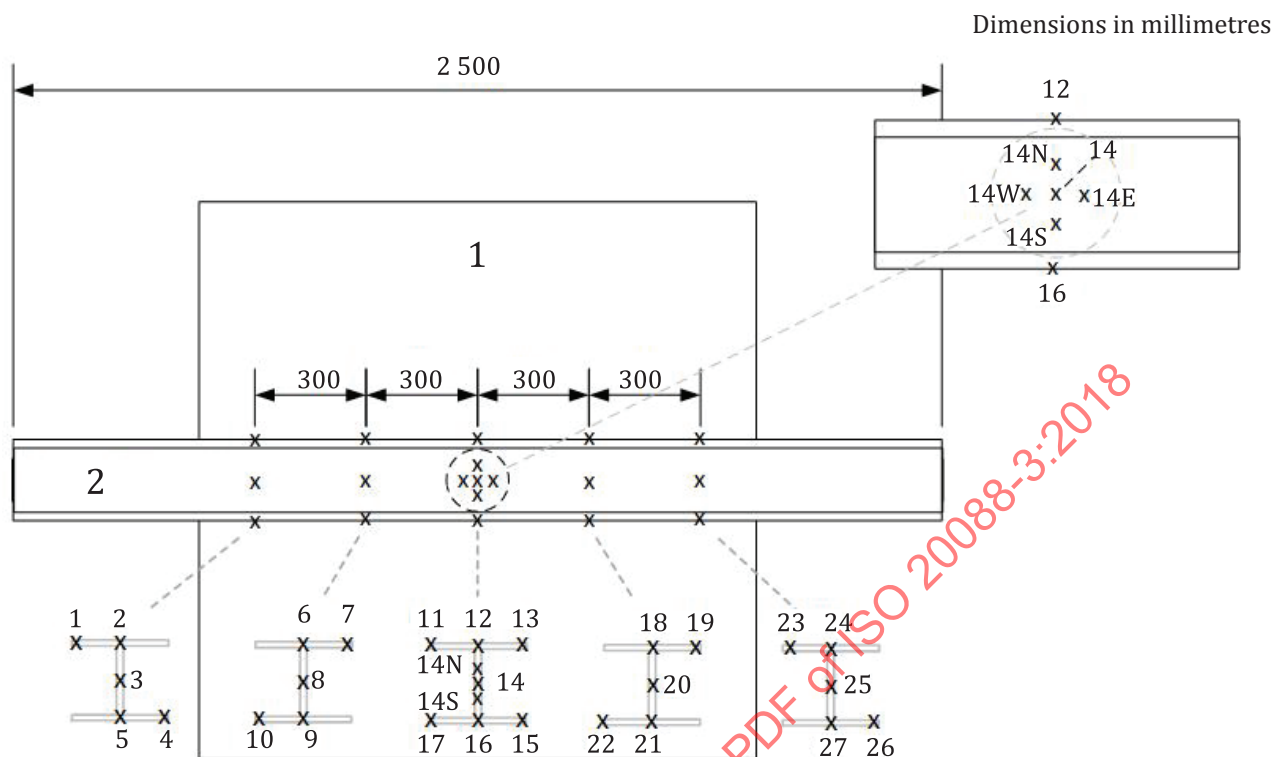
Thermocouples are positioned as shown in [Figure 5](#).

8 Test environment

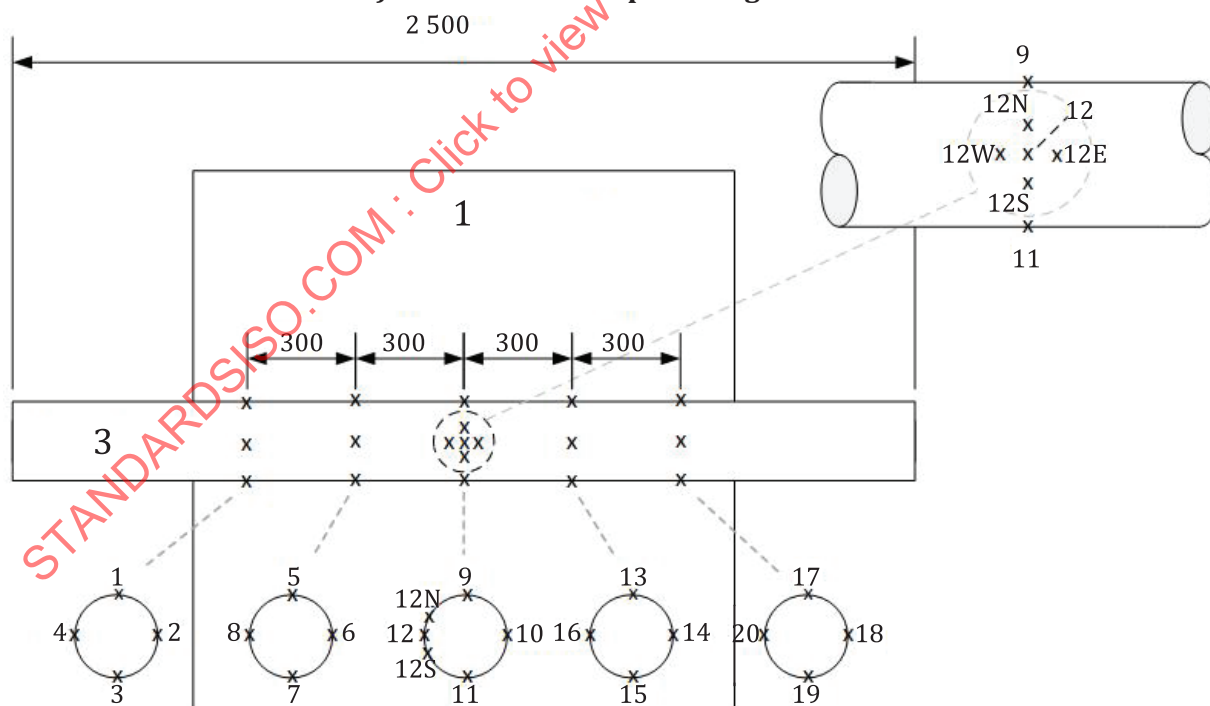
The test shall be preferably operated outdoor. If curing and conditioning is conducted under different conditions, it shall be clearly stated in the test report.

The test shall be carried out in an environment in which the effects of the weather do not significantly affect the test and the following conditions apply:

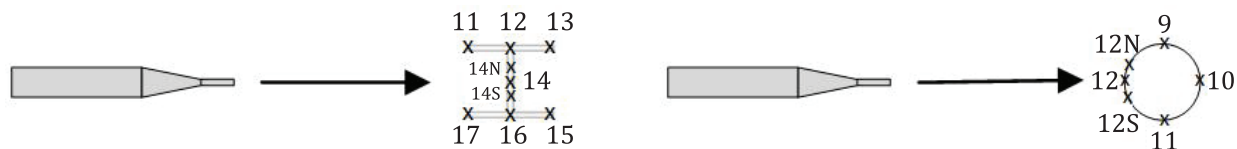
- the average temperature of the steel to be protected by the CSP material prior to testing shall be $(23 \pm 3) ^\circ\text{C}$ at the beginning of the test;
- outdoor temperature shall be within a range from $+10 ^\circ\text{C}$ to $+20 ^\circ\text{C}$ if no environmental chamber around the testing piece is to be utilized [otherwise an environmental chamber (3-sided plastic tunnel) is to be attached to the recirculation box with a length of 3 m in accordance with [Annex B](#)];
- outdoor relative humidity less than 60 % [otherwise an environmental chamber (3-sided plastic tunnel) is to be attached to the recirculation box with a length of 3 m in accordance with [Annex B](#)];
- no direct sunlight exposure;
- no direct exposure to atmospheric precipitation (includes rain, snow, sleet, hail).



a) Beam thermocouple configuration



b) Pipe thermocouple configuration



c) Orientation of jet with thermocouples at impingement location

Key

- 1 recirculation chamber
- 2 beam sample
- 3 pipe sample

Figure 5 — Thermocouple locations for beams and tubular specimens

9 Test procedure

A liquid nitrogen jet is released through a 10 mm orifice at a steady pressure between $(8 \pm 0,8)$ barg and a liquid temperature less than $-170\text{ }^{\circ}\text{C}$ (measured at the point liquid exits the schedule 40 pipe as described in [Figure 1](#)) impinging a test object placed 500 mm from the cryogenic jet release.

It is the responsibility of the test laboratory to ensure test parameters are maintained throughout the duration of the test.

The test procedure shall include the following.

- a) The test set-up should ensure that only the intended cryogenic jet release impinges the steel specimen, protected with CSP, from the start of the test (e.g. provide a deflector plate or nozzle until the liquid jet stabilizes with the required test parameters).
- b) Pressure and temperature readings at the nozzle are to be taken throughout the test. The temperature of the protected steel substrate is to be monitored throughout the test taking note of the locations of any sudden drop in temperature. The measurements are to be taken at every 1 s interval.
- c) The specimen owner shall provide the specimen for the test in a condition representative of its practical application. Specifically the test should feature the proposed joint geometry for preformed systems as described in [6.3](#).
- d) Photographs shall be taken of the test specimen before the test.
- e) The thickness of the CSP as well as the outer dimensions of the CSP system/assembly shall be verified by the independent testing laboratory prior to commencement of the test.
- f) Observations shall be recorded of significant details of the behaviour of the test specimen during the test and after the cryogenic jet release impingement ceases. Information on deformation or partial removal of the surface or cracking shall be noted.
- g) Photographs of the test specimen shall be taken as soon as is practicable after the end of the test to reflect the observations made in point f). These photographs shall be included in the test report.
- h) Provision should be made that a sample can be inspected within 5 min after termination of the test. Sample access time should be recorded.

10 Repeatability and reproducibility

The test method described in this document is expected to be repeatable and reproducible between test laboratories. It is the responsibility of the specimen owner to demonstrate that the test results of the sample(s) are representative of their CSP system including any joints and fixing details as well as the applicability to the specific structures to be protected.

11 Uncertainty of measurement

The overall uncertainty of the measurements shall be within the limits listed below. This shall include the uncertainty of the measuring sensors and logging system. Calibration testing shall show a level of confidence of at least 95 % with respect to known reference points and shall be traceable to international standards.

Temperature ± 5 °C or ± 2 %, whichever is greater.

Pressure $\pm 0,1$ barg or ± 2 %, whichever is greater.

12 Test report

The test report shall include the following information.

- a) The name of the testing laboratory, the date of the test, a unique test reference and report identification.
- b) The name(s) of the sponsor, the manufacturer and the product.
- c) Documentation on how and when the test specimen was prepared, details of the application of the CSP material (e.g. environmental temperature and humidity during application), the name of the application/installation company, if appropriate.
- d) A complete description of the test specimen, including measurements of the thickness of cryogenic spill protection material and the hardness, if measured; the mean, standard deviation and range of measurements of thickness should be given as well as details of any joint (if applicable) e.g. position, type, size of overlap and method of fixing.
- e) Construction drawings of the CSP system wherever possible.
- f) When appropriate, details of any deviations from the normal test configurations and the reasons for them.
- g) A record of test details and post cryogenic exposure characterization including:
 - 1) ambient conditions (e.g. air temperature, relative humidity, wind speed and direction);
 - 2) temperature and pressure at the nozzle;
 - 3) temperature of sample;
 - 4) for assemblies, a full inspection following the test to validate construction details and assess CSP performance (the assembly should be dismantled so that all components of the system can be checked for cryogenic penetration, integrity and general condition and a visual record made);
 - 5) the test result, given in the format
 - the appearance of the test specimen before and after the test and photographs,
 - the behaviour of the test specimen in case of cracking and/or unusual sound,
 - loss of CSP thickness,

- surface cracks,
- temperature/time graphs and spreadsheets of temperatures at no less than 30 s intervals for each thermocouple,
- temperature and pressure graphs at nozzle,
- temperature/time for each individual thermocouples, and
- an optional classification in terms of the type of specimen tested, critical temperature drop and period of resistance in accordance with [Annex C](#).

13 Practical applications of test results

13.1 General

The main purpose of the test is to determine the temperature drop in the steel substrate when subject to a cryogenic jet release. The cryogenic jet used for the test represents the combined cooling effect, momentum and penetration effects that are as close as possible to a realistic pressurized LNG release as described in the Scope. The test specimen is representative of the CSP used to protect steel work against cryogenic exposure of columns and beams found in structures supporting processes involved in the liquefaction of natural gas (e.g. the structural steel elements of an offshore liquefaction asset). The test arrangement was designed to determine the integrity and insulation effectiveness of the CSP when subject to the jet momentum and enhanced cooling of a sustained cryogenic jet release.

Although the procedure has been designed to simulate some of the conditions that occur in an actual cryogenic jet release it cannot produce all conditions exactly. The results of this test do not guarantee structural stability but can be used as an element of a cryogenic risk assessment for structures. On an informative basis, other testing may also take into account all the other factors that are pertinent to an assessment of the cryogenic hazard for a particular end use such as chemical resistance towards LNG, weathering, ageing, torsional flexing, loading, impact or explosion resistance or smoke production, to name a few.

The relevance of the test set up and results with regards to

- cryogenic liquid release scenario,
- location of the CSP on the structure,

shall be the responsibility of the end user. The acceptability of the test, in relation to the end use, can be subject to an independent verification authority (such as a class society if part of their scope) or remain at the discretion of the owner (or through delegation to the responsible design engineering company or consortium).

13.2 Performance criteria

13.2.1 General

The purpose of this test method is described in the Scope. It is not the purpose of this test method to provide guidance on the acceptability of a particular thickness of CSP for items such as free standing panels, nor the coating or method of assembly to be used.

A typical performance criterion for CSP is that the temperature of the protected structural element does not fall below a defined criterion (low temperature limit) within a specified cryogenic jet exposure time as specified by the sponsor.

Another criterion of performance provided by the test could be the time required to reach the limiting temperature as specified by the sponsor.

13.2.2 Coatings and spray-applied materials

13.2.2.1 Substrate temperature

The temperature time profiles at each measurement position shall be used to determine the temperature at each position reached during the test. The position and time of a sudden increase in the rate of temperature drop, if any, should be recorded as it may be indicative of possible failure of the CSP at that point. For the same reasons, the localized minimum temperature shall be reported in conjunction with the nearest cryogenic spill material thickness measurement.

13.2.3 Systems and assemblies

13.2.3.1 Substrate temperature

The temperature time profiles at each measurement position shall be used to determine the temperature at each position reached during the test. The minimum substrate temperature shall be reported. The position and time of any sudden increase in the rate of temperature drop, if any, should be recorded as it is indicative of possible failure of the system/assembly at that point.

13.2.3.2 Impairment of protection integrity

The penetration of liquid through any cracks, holes or breaches in joints shall be considered when assessing the integrity of a system. The amount of penetration and condition of the method of fixing can be evaluated in the following terms:

- a) evidence of liquid passing through the system with the fixing system becoming ineffective reflected by a localized fast drop in temperature;
- b) evidence of cold vapour passing through the system with the fixing system effective;
- c) no vapour passing through the system and with the fixing system effective;
- d) evidence of material dis-bonding.

If the temperature criterion is met, then a specimen meeting criterion c) clearly provides a wider safety margin than a specimen meeting criterion a). A statement of the criterion that is most appropriate should be included in the report.

13.3 Factors affecting the validity of the test

13.3.1 General

It is inevitable that, during some tests, there is a failure of control, instrumentation or of a seal. These are failures of the test procedure and do not indicate a failure of the test specimen. The most common failures are considered in [13.3.2](#) and [13.3.3](#).

13.3.2 Failure at nozzle

It can happen that the cryogenic jet release does not occur from the start of the test (e.g. failure of deflector arrangements). If visual confirmation of liquid release can be made from the temperature measurement as stated in [Clause 9](#) (<-170 °C temperature), including the time at which the liquid was present, the test may be considered valid.

13.3.3 Failure of thermocouples

Up to three thermocouples can fail (e.g. can be shown not to be measuring temperature with the required accuracy) during a test and the test still be considered valid provided that the thermocouple

position(s) do not correspond to the area of greatest damage or at the impact point of the jet. Only two thermocouples are allowed to fail at the impact point of the jet.

Failure of thermocouples directly underneath a joint as described in [6.3](#) will terminate the test if the largest temperature drop is shown along the line of the joint.

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Annex A (normative)

Methods of fixing thermocouples

A.1 General

Chromel/alumel (type K) thermocouples, with conductors of a diameter appropriate to the method of fixing shall be used. Thermocouples shall be attached in accordance with one of the methods given in [A.2](#) to [A.4](#).

A.2 “Quick Tip” attachment

Place the two 0,3 mm diameter thermocouple wires into a metal piece with pre-drilled holes for the wires. Squeeze the metal piece in a special tool into a cylindrical shape, 1,5 mm long and 1,5 mm in diameter, firmly gripping both wires in the process. Drill a 2 mm hole, 2 mm deep, in the position where the thermocouple is to be fixed. Place the joint piece in the hole and use a drift to peen over the metal.

A.3 Capacitive discharge welding

Equipment, suitable for attaching thermocouples to a metal substrate, shall be used. Follow the manufacturer's instructions in preparing the surface and attaching the thermocouple.

NOTE Small pieces of stainless steel shim can be spot welded over the thermocouple to add mechanical strength and prevent stress being placed on the junction.

A.4 Drilling and peening

This method shall be used for attaching sheathed or welded junction thermocouples to a metal substrate. If the thermocouple has separate wires, weld them together. Drill a hole of appropriate diameter in the position in which the thermocouple is to be attached with a maximum depth of 5 mm. Insert the thermocouple and peen over the edges of the hole with a centre punch.

A.5 Front face attachment

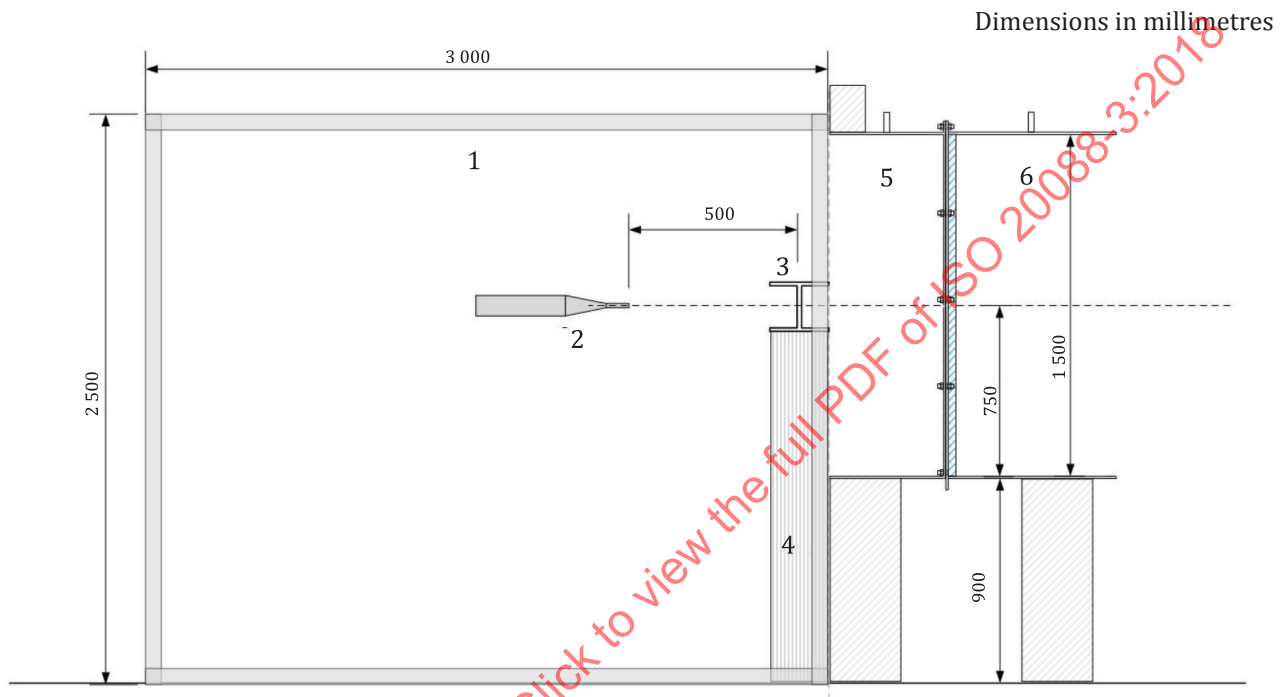
The surface thermocouples shall be attached to the sample by means of adhesive tape designed to work under cryogenic conditions. Pieces of this tape (approximately 25 mm × 150 mm) shall be placed on top of the thermocouple wire every 300 mm to ensure that the wire is retained close to the surface of the sample. The adhesive tape shall be pressed onto the surface of the sample as tightly as possible. The measuring end of the thermocouple shall be raised from the surface of the sample by (8 ± 2) mm.

NOTE Small pieces of stainless steel shim can be spot welded over the thermocouple to add mechanical strength and prevent stress being placed on the junction.

Annex B (normative)

Complete set-up

The technical drawing set-up is displayed in [Figures B.1](#), [B.2](#) and [B.3](#).



Key

- 1 environmental chamber
- 2 nozzle ($8 \pm 0,8$) barg (average pressure $\pm$ standard deviation)
- 3 specimen (beam shown)
- 4 specimen (and recirculation chambers) supports
- 5 recirculation chamber (insulated on back surface)
- 6 back box (support and stability)

Figure B.1 — Overall side dimensions with H beam: Beam configuration (side view — including environmental chamber)