TECHNICAL REPORT

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Determination of the resistance to jet fires of passive fire protection —

Part 2: Guidance on classification and implementation methods

Détermination de la résistance aux feux propulsés de protection passive contre l'incendie —

Partie 2: Directives relatives à la classification et aux méthodes de mise en oeuvre

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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. www.iso.org/directives

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The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

ISO 22899 consists of the following parts, under the general title *Determination of the resistance to jet fires of passive fire protection materials* —:

— *Part 1:General requirements*

— *Part 2: Guidance on classification and implementation methods* [Technical Report]

Introduction

The jet fire test described in ISO 22899-1 is one in which some of the properties of passive fire protection materials can be determined. The test specified in ISO 22899-1 is designed to give an indication of how passive fire protection materials will perform in a jet fire. Although the test method has been designed to simulate some of the conditions that occur in an actual jet fire, it cannot reproduce them all exactly and the thermal and mechanical loads do not necessarily coincide. The results of the jet fire test do not guarantee safety but may be used as elements of a fire risk assessment for structures or plant. One should also take into account all the other factors that are pertinent to an assessment of the fire hazard for a particular end use. The jet fire test is not intended to replace the hydrocarbon fire resistance test (ISO/TR 834-3; EN 1363) but is seen as a complementary test.

Determination of the resistance to jet fires of passive fire protection —

Part 2:
Guidance on classification and implementation methods

1 Scope

The test specified in ISO 22899-1 is designed to give an indication of how passive fire protection materials will perform in a jet fire.

This part of ISO 22899 provides:

— background information on the applicability and validation of the jet fire test;

— further details on testing pipe penetration seals;

— guidance on the interpretation of the tests results and on an optional classification system;

— guidance on the combination of results from hydrocarbon furnace tests and resistance to jet fire tests.

ISO 22899-1 describes the thickness of fire protection material (sometimes referred to as passive fire protection; PFP) required to resist the application of a 'jet fire'. This part of ISO 22899 provides information on the 'erosion factor' which is the additional thickness required above and beyond that required to satisfy the relevant criteria of ISO 834 (or other national or regional standards designed to evaluate the fire resistance with respect to a fully developed fire) for the element/construction under test.

2 Normative references

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

ISO 22899-1, *Determination of the resistance to jet fires of passive fire protection materials — Part 1: General requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22899-1 and the following apply.

3.1
critical temperature
maximum temperature that the equipment, assembly or structure to be protected may be allowed to reach

3.2
critical time
minimum time required to reach the critical temperature

3.3
erosion factor
extra thickness of passive fire protection required when comparing the results from a jet fire test with those from a furnace test on specimens with a similar section factor (e.g. 100 m^{-1}) and period of fire resistance, the critical temperature or critical time or both

3.4
integrity
ability of a fire barrier to prevent the transmission of flame, smoke, hot and toxic gases

3.5
section factor
ratio of the area per unit length of steel exposed to fire divided by the volume per unit length of the section

Note 1 to entry: The lower the section factor, the slower the rate of heat increase for a given volume of steel. See 9.2 for a more detailed explanation.

4 Symbols and abbreviated terms

A	Heated area per unit length (m^2)
k_0, k_1, k_2	Coefficients of linear regression
S_f	Section factor (m^{-1})
t_{final}	Time (rounded to the nearest half minute) from jet ignition to final jet extinguishment.
$t_{resistance}$	Period (rounded down to the nearest half minute) of fire resistance
$T_{ambient}$	Average initial substrate temperature (°C)
$T_{critical}$	Critical temperature or critical temperature rise (°C)
$T_{maximum}$	Maximum temperature during test (°C)
$T_{tolerance}$	Tolerance (usually 5 °C) on the allowed temperature rise
V	Volume per unit length (m^3)
w	Fire protection coating thickness (mm)

5 Principle

The objective of the jet fire test is to establish the additional amount of passive fire protection material that needs to be applied to a structural member, valve, penetration sealing system, etc., in order to resist exposure to a jet of ignited fuel, above and beyond that needed to satisfy the criteria of the ISO/TR 834-3 hydrocarbon fire resistance test. This additional thickness of material, known as the erosion factor, is determined once for each similar element or construction, which may be added to the thickness of material determined for a similar range of such elements, when evaluated for fire resistance against the methods given in ISO/TR 834-3 using the principles provided below.

The method provides an indication of how passive fire protection materials perform in a jet fire that may occur, for example, in petrochemical installations where ignitable gases are stored at pressure. It aims to simulate the thermal and mechanical loads imparted to passive fire protection material by large-scale jet fires resulting from high-pressure releases of flammable gas, pressure liquefied gas or flashing liquid fuels. Jet fires give rise to high convective and radiative heat fluxes as well as high erosive forces. To generate both types of heat flux in sufficient quantity, a 0,3 kg s^{-1} sonic release of gas is aimed into a shallow chamber, producing a fireball with an extended tail. The flame thickness is thereby increased and hence so is the heat radiated to the test specimen. Propane is used as the fuel since it has a greater propensity to form soot than does natural gas and can therefore produce a flame of higher luminosity. High erosive forces are generated by release of the sonic velocity gas jet 1 m from specimen surface. The jet velocity is ca. 100 ms^{-1} at 0,25 m from the back of the flame recirculation chamber (e.g. the front of the web of a structural-steel specimen) and ca. 60 ms^{-1} at the back of the chamber. The average heat flux is approximately 240 kW m^{-2} and the maximum heat flux 300 kW m^{-2}.[1] The heat fluxes are highest in the upper part of the chamber and lowest in the corners and at the jet impact zone. The combination of fuel, release rate and experimental arrangement is intended to apply a similar heat loading to the specimens as would be given by a 3 kg s^{-1} natural gas (60 bar, 20 mm orifice) jet fire released 9 m (the distance for the most severe combination of erosive forces and heat transfer) from a target (see Clause 6).

6 Applicability of the test

6.1 General

The background to the development and applicability of the test is provided to give the basis for the principles of the test.

6.2 Jet fires

The main sources of detailed information on the characteristics of jet fires are the reports on the two programmes of jet fire research co-funded by the European Community. These programmes studied single fuel natural gas and propane jet fires,[2] and jet fires fuelled by mixtures of natural gas and butane.[3][4] The results of large-scale experiments to study natural gas jet fires impacting onto a large flat surface have been published.[5] The fuel release rates involved in these experiments ranged up to 12 kg s^{-1}, at release pressures of up to 60 bar. Measurements included the flame size and shape and thermal radiative properties, flame velocities and temperatures in some experiments, and in the impacting experiments, the total and radiative heat fluxes incident upon the target at different locations (using instruments maintained at a nominally constant temperature of 60 °C).

Although a formal peer reviewed interpretation of the whole range of experimental data is not available, the basic information on the heat loading for different types of fire has been accepted by industry experts and summarized.[6] General observations are made here.

— Experiments involving jet fires impacting on a pipe or a vessel demonstrated that the heat fluxes incident upon the target varied considerably over the surface of the object, and also varied depending on how far the target was from the release point. Such variations can be caused by variations in the velocities of the gases passing over the object (influencing the convective component of heat flux) or the amount of thermal radiation incident upon different parts of the surface.

— Four different natural gas release types were studied in the initial EC-supported Project AA,[2] with different pressures and release rates. The experiments covered flow rates from 2,5 to 8,5 kg s^{-1}, and pressures up to 60 bar. For this range of conditions, the maximum total heat fluxes were similar, typically 250 kW m^{-2}, increasing to 320 kW m^{-2} for positions towards the end of the flame. However, there were significant detailed variations in the areas engulfed, and in the distribution of the heat fluxes and the balance between the radiative and convective components.

— Other experiments were carried out as part of that project involving two-phase propane releases, with flow rates in the range 2 to 12 kg s^{-1} at discharge pressures of 20 bar. The fires generated were found to be more strongly radiative than the natural gas jet fires, but the heat fluxes incident upon a target had a lower convective component, the overall effect being to give lower maximum total heat fluxes.

— A further series of experiments (all with a total flow rate of nominally 2,5 kg s^{-1}) were carried out as part of the EC-supported Project JIVE[3,4] with jet fires fuelled by mixtures of natural gas and butane. The aim was to investigate the balance between radiative and convective components and to identify whether a worst case existed for which the total heat fluxes were at a maximum.

The results of these experiments showed that although the radiative properties of the fires increased with increasing butane concentration, the maximum total heat fluxes were in a similar range to the earlier Project AA[2] natural gas and propane fire experiments.

The EC-supported programmes generated experimental data for horizontal jet fires. Information is available for free vertical fires, and for natural gas fires impacting vertically onto a flat plate.[5] The results show that although there are major variations in the distribution of incident heat fluxes, in general the maximum values were no greater than the maximum values observed in the horizontal jet fire experiments.

Larger flow rates at similar pressures may be expected to give similar velocities to the releases already studied. The initial gas exit velocities for sonic releases will be equal. However, higher pressure releases will tend to maintain higher velocities over greater distances. Similarly, the flame temperature is dependent primarily on the fundamental combustion properties of the fuels, and again may not increase significantly with increasing flow rate.

6.3 Large scale testing of passive fire protection

Based on the results of the EC-funded programmes, one of the natural gas fires was subsequently chosen[7] as the basis of a large scale demonstration of the resistance to jet fires of passive fire protection. This natural gas jet fire comprised a release of 3 kg s^{-1} at a discharge pressure of 60 bar through a circular hole of diameter 20 mm. This test was considered to be representative of the range of single fuel natural gas, propane and butane jet fires studied, with the advantage that the flow rate and pressure met the practical requirements for a test which could be carried out at the site for long durations. The maximum heat fluxes generated by this release were either similar to, or higher than, the maximum heat fluxes generated by any of the releases in the EC-supported programmes. The release was at the highest pressure studied, and consequently maintains higher velocities over a greater distance. It was therefore expected to be a more severe test than one in which the heat fluxes were similar but with a greater radiative component, since the erosive effect of higher velocities on a test material would be greater. Similar considerations led to the distance from the release hole to the target being the closest characterized in the previous work (9 m), where the gas velocities and hence the erosive effect, would be greater than for positions further away. The long duration jet fire test differed only in detail from the fires characterized previously, principally in that the position of the release hole could be altered during a test to maintain the engulfed region constant during a test, which would otherwise have been affected by changes in wind conditions.

6.4 Development

To provide a test of fire protection materials or systems at a scale which is more manageable (and cheaper), and which can be carried out under more controlled conditions (in particular, wind conditions), a medium scale jet fire test was developed,[1],[8] which has been used to examine the performance of a number of materials in jet fires. The test is based on an ignited sonic release of gaseous propane with mass flow rates up to 0,3 kg s^{-1}. Since this work had indicated that this medium scale jet fire test could reproduce the key conditions found in large scale jet fires, it was considered possible that it could be used as a ‘standard jet fire test’. In order to develop this further, an international working group was set up under the auspices of the United Kingdom Health and Safety Executive (HSE) and the Norwegian Petroleum Directorate (NPD). This working group had the objective of producing a test procedure for jet fire testing fire protection materials.

Large flames produced by high pressure, high velocity, sonic gas jets give rise to high convective heat fluxes as well as high radiative heat fluxes. A sonic gas jet is also used in the medium scale Jet Fire Resistance Test,[8] since it is desirable to examine the combined effect of both types of heat flux on passive protection materials. To generate both types of heat flux in sufficient quantity, a 0,3 kg s^{-1} sonic release of gas is aimed into a shallow box, producing a fireball with an extended tail, thereby increasing the flame thickness and hence the heat radiated to the test specimen, comprising the rear wall of the box.[1] Propane, chosen as a convenient fuel for a medium scale test, has a greater propensity to form soot than does natural gas and can therefore produce a flame of higher luminosity. Without the box creating recirculation and producing the fireball and the higher luminosity of the propane flame, it would not be possible to achieve the high radiative heat flux found in the much larger jet fires. Heat flux measurements using gauges maintained at 60 °C have shown[1] that an area average total flux of 240 kW m^{-2} is achieved on the rear wall of the box with a maximum value of about 300 kW m^{-2}. Measurements of radiation flux alone were also made and found to be about 50 % of the maximum total flux. Velocity measurements are not available for comparison with the large scale experimental data, however, significant velocities (ca. 60 m s^{-1} 1m from the release) are known to be present because of the relatively high convective heat fluxes measured, and the observation that test specimens can suffer physical damage from erosion effects. Claims of heat flux values much greater than 300 kW m^{-2} at any scale, fuel type, or combination have not been substantiated.

In 1996, OTI 95 634 "Jet fire resistance test of passive fire protection materials"[8] was issued, replacing the earlier OTO 93 028 "Interim jet fire test for determining the effectiveness of passive fire protection materials"[9]. The United Kingdom, Health and Safety Executive (HSE) issues Offshore Technology reports in a series of publications, namely:

— OTO – These publications, known as Offshore Technology Order reports, are made available by the HSE as part of a series of reports of work which has been supported by funds formerly provided by the United Kingdom, Department of Energy and lately by the HSE.

— OTI – These publications, known as Offshore Technology Information reports, are published by the HSE as part of a series of reports of work which have been supported by funds provided by the Executive. Background information and data arising from research projects are published in the OTI series of reports.

6.5 Applicability

As discussed above, the jet fire resistance test may be regarded as representative of a large scale natural gas jet fire test used[7] to test fire protection materials and systems. The thermal characteristics of the large scale test may also be considered to a first approximation to be representative of other large scale jet fires studied, involving releases of pressurized gaseous fuels. There are reasons to believe that the natural gas jet fire test[7] is likely to be a more severe test than other natural gas jet fires of either lower flow rates at similar pressures (because the radiative component will be less) or similar flow rates at lower pressures. Similarly, the test is likely to be more severe than comparable releases of liquids such as propane or butane, which vaporize readily upon release.

While the jet fire resistance test was originally developed for offshore applications, HSE sponsored a test programme to see if it was equally valid for onshore applications. The test programme[13] involved approximately 1,7 kg s^{-1} flashing liquid jet fire engulfment of 2 tonne propane tanks protected with a passive fire protection material designed to give 90 min protection. Jet Fire Resistance Test specimens were prepared to the same specification and tested. Broadly similar results were found to those obtained with engulfment of the tanks by the flashing liquid propane jet fire, indicating that the appropriate version of the Jet Fire Resistance Test can be used for onshore applications.

There are concerns regarding the application and performance of passive fire protection materials and products when subjected to extreme fire events. Limited information is available about how passive fire protection materials and products (developed for buildings only to withstand relatively slow build up fire tests such as the ISO 834 standard fire) if subjected to a fire exposure significantly more severe. A fire protection material or system intended to withstand a conventional building fire for a specified period may not perform adequately in an extreme event scenario. Products that have demonstrated the ability to withstand a jet fire can be used to protect structural elements and installations against extreme fires.

The experimental data upon which the above discussion is based was obtained for free jet fires impacting in the open onto a range of different targets. The experiments do not represent fires in areas of significant confinement, for example where the ventilation rate allows insufficient air for complete combustion ("ventilation-controlled"). The behaviour of such fires may be very different from the free flame equivalents.[14] Radiative heat fluxes may be higher than the equivalent free flames, because reduced heat loss from confined fires can result in higher gas temperatures, ventilation-controlled fires can produce more soot and hence increase the flame emissivity, and creation of a recirculating flame can increase the radiative path length through the flame. However, in many practical situations offshore, releases may occur in areas of partial confinement, where these effects would be limited. In those cases, the large scale natural gas jet fire test (and hence the resistance to jet fires test) may be considered to be a reasonable test of materials which will be used in practical situations.

There are certain types of release whose likely effects on fire protection materials cannot be regarded as being represented by the large-scale natural gas jet fire test (and hence the resistance to jet fires test). The thermal properties of jet fires of liquid higher hydrocarbon fuels such as crude oil, or jet fires fuelled by mixtures of natural gas and liquid higher hydrocarbon fuels, may be significantly different from those of the gaseous fuels studied. Even if the thermal properties of such fires are considered similar to those of the long duration test, the effects of liquid fuels impacting onto fire protection materials, and possibly penetrating the outer layers, will not be represented. The jet fires studied were all generated by releases of pure fuels, whereas in many realistic scenarios offshore, contaminants such as water or sand may be present. The effects of water will tend to reduce the severity of the thermal properties of the fires, and may even be sufficient to prevent combustion. However, the presence of solid materials such as sand may have a strongly erosive effect on fire protection materials or systems which will not be represented by either the large scale natural gas jet fire test or the resistance to jet fires test.

6.6 Conclusions from the validation trials

a) The medium scale resistance to jet fire test may be considered to be representative of the conditions experienced by fire protection materials or systems in the large scale, long duration natural gas jet fire test.

b) The large scale test may be regarded as representative of free jet fires of gaseous fuels at similar pressures and flow rates.

c) Fires fuelled by releases at lower pressures and from smaller release orifice (and therefore flow rates) will be smaller, and will tend to be less severe tests of fire protection materials. Although larger release holes (and therefore greater flow rates) and higher pressures will result in larger fires, and may produce more severe conditions, the effects of scale will tend towards limiting values which may not be significantly more severe than the large scale test.

d) Confined fires may produce higher total heat fluxes, but in practical situations of partial confinement, conditions are unlikely to be produced which are a significantly more severe test of fire protection materials than the unconfined large scale test (and hence the resistance to jet fires test).

The fire tests cannot be regarded as representative of conditions other than jet fires of gaseous fuels. Both the effects of liquid fuel impacting and burning on the fire protection material itself, and the erosive effects of solid contaminants such as sand in the fuel, are unknown.

7 Additional information on testing pipe penetration seals

7.1 General

In ISO 22899-1, a procedure is given for testing pipe penetration seals in the external configuration, i.e. mounted on a tubular section in front of the flame re-circulation chamber. While testing in this configuration gives valid results, it was considered advisable to develop an internal configuration version of the test (i.e. pipe penetration through the back face of the flame re-circulation chamber) as it allows:

— direct observation of any loss in integrity; and

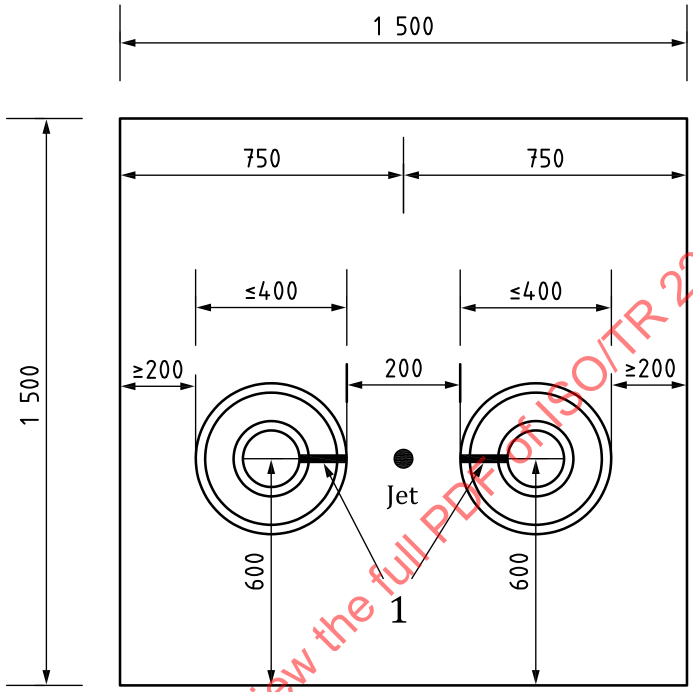
— mounting of the through pipe independently of the fire barrier as required in the International Maritime Organization, Fire Test Procedures(FTP Code).[15]

7.2 Recommendations for mounting penetration seals on panels

A jet-fire fire resistant panel, which includes either one or two pipe penetrations, should be constructed in accordance with ISO 22899-1. The panel should be fixed to act as the rear wall of the flame re-circulation chamber which is described in ISO 22899-1. The connection between the panel and the box should be sealed to prevent passage of hot gases, for example, using soft mastic or ceramic fibre. The side, top and bottom walls of the flame re-circulation chamber should be protected by a ceramic board insulation material or other suitable passive fire protection material.

The pipe penetrations should be positioned no closer than 200 mm from sides of the flame circulation chamber and the separation between adjacent penetrations should be 200 mm. Both measurements should relate to the distance to the nearest part of the penetration, including any insulation which is part of the system. When testing two penetrations, the centres of the penetrations should be 600 mm from the bottom of the inner surface of the flame re-circulation chamber and the jet should be aimed mid-way between them. If testing a single penetration, either the left or the right position may be used and the other left blank. When testing sleeve-type penetrations, the longitudinal join should be positioned so that it faces the jet impact point. The relative positions are illustrated in Figure 1.

Dimensions in millimetres



Key

1 longitudinal joint in sleeved seal

Figure 1 — Positions of panel mounted pipe penetration seals relative to the jet

A pipe penetration system consists of a seal which fits between a collar mounted on the rear wall of the flame recirculation chamber and a pipe of smaller diameter which passes through the collar. The rear wall of the flame recirculation chamber may be made from 10 mm steel or it may be representative of its practical application, for example a bulkhead welded into a fire wall. If the rear wall is made from steel, then all exposed areas of this plate may be protected with, for example, a ceramic board or PFP coating to prevent warping and heat transfer. The insulation should be representative of a system or material that would be used in practice. Alternatively, the test may be carried out without insulation on the rear wall of the flame recirculation chamber or with insulation on the non-fire side of the rear wall.

Whatever arrangement is chosen, the specimen should be constructed in a manner that is representative to the construction that will be used in practice. The collar is fixed to the rear wall such that it protrudes 50 mm from the front surface of the substrate and either 50 mm from the rear surface for a sleeved seal or a distance sufficient to allow the normal packing length to be used for a packed seal. The collar should have a maximum outer diameter of 356 mm (representative typical standard pipe sizes). A smaller diameter pipe passes through the collar such that it extends a maximum of 300 mm from the front of the substrate. The inner pipe should have a maximum diameter of 273 mm (representative of typical standard pipe sizes) and at the end should be capped with a 6 mm steel plate. The end cap and any exposed surfaces of the inner pipe should be protected using ceramic board or PFP to prevent heat transfer. The inner pipe is supported centrally within the hole by means of a frame attached inside the protection chamber. The framework should support the inner pipe such that some movement can occur between pipe and collar. The pipe penetration seal is fitted between the collar and the pipe which penetrates it (see Figure 2). If the seal incorporates a joint, it should be orientated facing the jet impingement point. General views of the mounting of sleeved and packed seals are illustrated in Figure 2.

Dimensions in millimetres

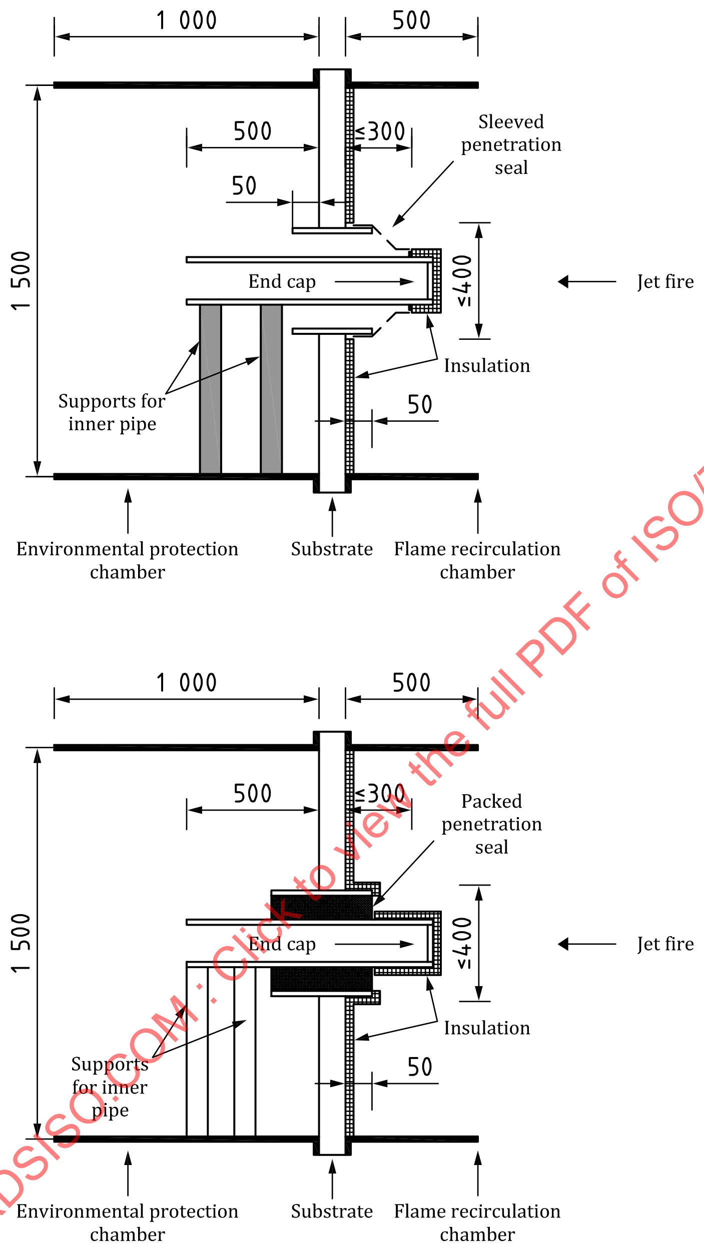


Figure 2 — General view of panel mounted and packed pipe penetration seal

7.3 Recommended instrumentation of pipe penetration seals

For pipe penetration seals, two thermocouples are recommended to be fixed on the unexposed face at each of the following locations:

— On the surface of the collar at a distance of 25 mm from the centre of the thermocouples to the position where the collar emerges from the rear of the substrate;

— On the surface of the pipe at distance of 25 mm from the centre of the thermocouples to the position where the pipe emerges from the rear of the collar.

For each of the positions indicated above, one of the thermocouples should be fixed directly above the centre of the collar or pipe and the other thermocouple should be fixed directly below the centre of the collar or pipe.

Two additional thermocouples are recommended at positions dependent upon the type of the pipe penetration:

a) For sleeved seals with a longitudinal join, thermocouples should be mounted on the surface of the pipe behind the join, 25 mm from each end of the seal;

b) For packed seals, on the surface of the rear of the packing, mid-way between the pipe and the collar, one above and one below the pipe.

Additional thermocouples may be needed, dependent upon the complexity of the pipe penetration. The thermocouple positions are illustrated in Figure 3.

Dimensions in millimetres

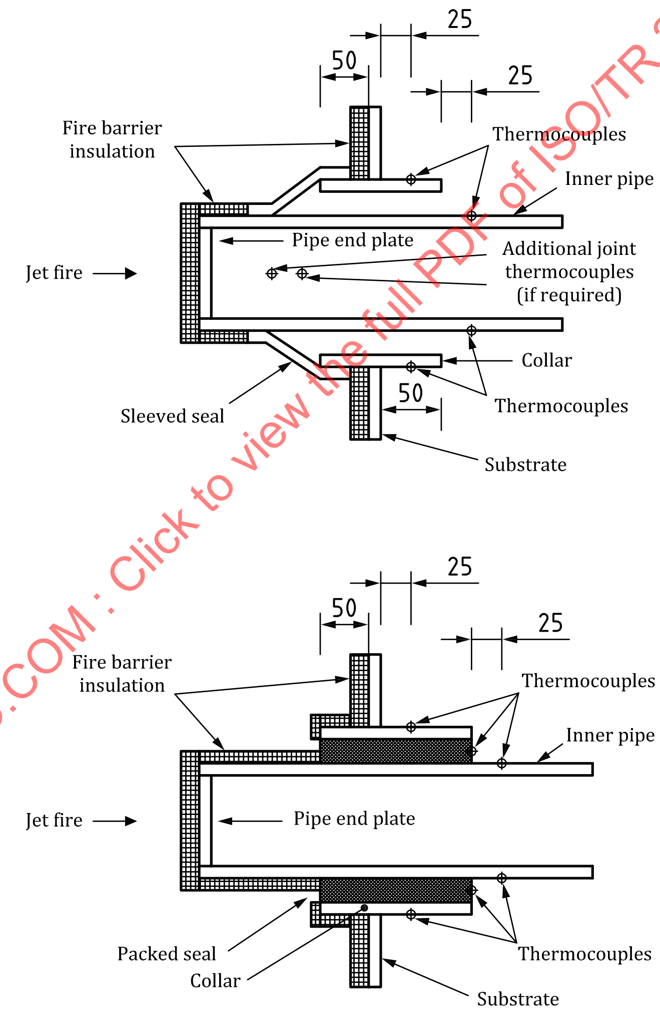


Figure 3 — Thermocouple positions for sleeved and packed pipe penetration seals

7.4 Recommended performance criteria

The performance of pipe penetrations may be related to their ability to satisfy both the insulation and the integrity criteria. Since the pipe penetration is a local weakness in the fire barrier, it should be capable of preventing a temperature rise at any point on the surface not exceeding 180 °C above the initial temperature, i.e. the insulation criteria is not met if the maximum temperature rise is > 180 °C. The average temperature rise is not relevant. The integrity of the system is determined by examination of the seal after the test. Signs (e.g. scorching, melting – see 8.5) of flame break through and passage of hot gases are indicative of loss of integrity.

8 Classification (optional)

8.1 General

Where the intended use requires it, an optional classification may be made. The classification should be related to the type of application and based on the maximum temperature rise observed during the test and the period of exposure to the jet fire. The procedure used is based on that proposed in ISO 13702. The classification rating is specified as:

Type of fire / Type of application / Critical temperature rise (°C) / Period of resistance (minutes)

These are considered as follows.

8.2 Type of fire

ISO 13702 distinguishes between “standard fires” (cellulosic fires – referred to in the standard) (CF), hydrocarbon pool fires (HC) and jet fires (JF). As suggested in ISO 13702, the letters JF represent the type of fire used in this test. The other designations are mentioned as it is likely that some fire scenarios may be specified in the form of a jet fire followed by a hydrocarbon pool fire. In practice, it is not easy to perform combined jet fire and furnace tests on the same specimen and hence a method of combining the results is required (see Clause 9). In such cases, the type of fire and its duration should be specified. The critical temperature rise will be the overall allowable temperature rise. Hence, for a fire barrier designed to withstand a 15 min jet fire followed by a 30 min hydrocarbon pool fire with a critical temperature rise of 140 °C, the rating would be:

(JF+HC) / Type of application (for example, Fire barrier) / 140 °C / (15_{JF} + 30_{HC})

8.3 Type of application

The specimen tested will depend on the practical application being considered. The most common types of application are:

— structural steel;

— pressure vessels;

— equipment with hot surfaces;

— pipes;

— safety critical control units;

— fire barriers (for example, divisions, walls, floors, bulkheads, decks, etc.);

— cable transit systems; and

— pipe penetration seals.

The application should be specified in the form indicated above. Where the test is used for another other type of application (e.g. control panel, emergency shut down valve, inspection hatch), this should be specified in a similar way.

8.4 Critical temperature rise

Each application will have its own critical temperature ($T_{critical}$), i.e. a maximum acceptable temperature before failure is likely to occur. Examples of typical critical temperatures are given in ISO 13702, Annex C.

The critical temperature rise is defined, in advance of the test, according to the protection criteria for the equipment, assembly or structure being protected. For some items, the critical temperature may be an absolute temperature (e.g. the temperature at which a safety critical control panel will fail in a fire), and for other items, such as fire barriers, a critical temperature rise over a specified duration is given (e.g. at least 60 min for a temperature rise of 140 °C). In practice, for items with an absolute critical temperature, this is treated as a temperature rise above the initial substrate temperature.

8.5 Period of resistance

The test duration is specified as an exposure time, and the period of exposure should start from the time the jet fire fuel is ignited and the period of fire resistance should be taken as the time at which the maximum allowable temperature criteria are exceeded. For the optional classification application, the period of resistance should be rounded down to the nearest 5 min. The most common periods of resistance used are 15, 30, 60, 90 and 120 min. Other increments may be used. For non-classification applications, the actual exposure time should be recorded.

8.6 Integrity

For fire protection materials and systems with joints (e.g. transit systems, fire barriers), it is important that the transmission of flame, smoke, hot and toxic gases be prevented, i.e. that their integrity is maintained. If integrity requirements are part of the classification procedure in all cases for systems with joints, it is recommended that additional thermocouples are placed behind the joints to determine if there are any sudden increases in temperature indicative of breakthrough of flames or hot gases and smoke. When practicable, provision should be made for video recording the rear of any joints. Other techniques, such as thermal imaging, may also be used. If it is necessary to measure the concentration of toxic gases produced, the rear of the environmental chamber can be sealed and the gases produced extracted at a known rate past concentration sensors.

8.7 Examples of application of the rating

In deriving the rating, it is necessary to take into account the practical requirement to measure the time to achieve a critical temperature ($T_{critical}$) or a specific rise above the initial average substrate temperature ($T_{initial}$) A 5 °C tolerance ($T_{tolerance}$) is allowed in measuring the temperature rise. A number of cases are provided in order to illustrate the classification procedure.

Case 1. Control panel with absolute critical temperature of 65 °C and minimum time of 15 min

Test duration specified in terms of critical temperature	= $T_{critical}$ = 65 °C
Average initial substrate temperature	= $T_{initial}$ = 10 °C
Temperature measurement tolerance	= $T_{tolerance}$ = 5 °C
Allowable actual substrate temperature rise	= $T_{ambient}$ + $T_{critical}$ + $T_{tolerance}$ = 10 °C + 65 °C + 5 °C = 80 °C
Time to reach 80 °C	= 16,5 min
Fire rating	= 15 min (rounded down to nearest 5 min)
Rating	JF / Control panel / 65 °C / 15 min

Case 2. Fire barrier with a critical temperature rise of 140 °C and minimum time of 60 min

Test duration specified in terms of critical temperature rise	= $T_{critical}$ = 140 °C
Average initial substrate temperature	= $T_{initial}$ = 10 °C
Temperature measurement tolerance	= $T_{tolerance}$ = 5 °C
Allowable actual substrate temperature rise	= $T_{ambient}$ + $T_{critical}$ + $T_{tolerance}$ = 10 °C + 140 °C + 5 °C = 155 °C
Time to reach 155 °C	= 57,5 min
Fire rating	= 55 min (rounded down to nearest 5 min)
Rating	JF / Fire barrier / 140 °C / 55 min (the 55 min requirement is met but not the 60 min requirement)

Case 3. Structural steel with a critical temperature of 400 °C and minimum time of 120 min with the jet fire interrupted for 5 min after one hour due to failure of fuel supply.

Test duration specified in terms of critical temperature	= $T_{critical}$ = 400 °C
Average initial substrate temperature	= $T_{initial}$ = 10 °C
Temperature measurement tolerance	= $T_{tolerance}$ = 5 °C
Allowable actual substrate temperature rise	= $T_{ambient}$ + $T_{critical}$ + $T_{tolerance}$ = 10 °C + 400 °C + 5 °C = 415 °C
Time to reach temperature of 415 °C	= (127,5 – 5,0 min interruption) = 122,5 min
Fire rating	= 120 min (rounded down to nearest 5 min)
Rating	JF / Structural steel / 400 °C / 120 min

9 Combination of results from hydrocarbon furnace and resistance to jet fire tests

9.1 General

The jet fire test is complementary to furnace testing and the results from both types of test should be taken into account when assessing the effectiveness.

9.2 Hydrocarbon and jet fire resistance tests

Although protection against a “standard” fire (e.g. from timber, paper or cotton), has historically dominated the commercial and industrial fire scenes, it is not very representative of a fire on a process plant involving spilled or pressure released hydrocarbons. This is because a fire involving cellulosic materials grows relatively slowly compared to a hydrocarbon fire. Various national and international fire tests of fire protection products exist, which are based on hydrocarbon fires. These are mainly furnace tests which expose a sample to a pre-determined heat-up regime while monitoring the thermal response on the reverse side of the sample. A typical standard for furnace testing is ISO 834 (see Part 3 for the hydrocarbon fire test curve). A standard fire test provides a reproducible time/temperature heating regime within which the response of test specimens can be assessed against various criteria. While hydrocarbon furnace tests are designed to represent a particular type of fire, they do not reproduce the actual fire conditions. The furnace temperature and total heat flux may be similar to those generated within a fire but parameters such as

— the balance between radiative and convective heat transfer,

— pressure fluctuations due to turbulence,

— erosive forces from high gas velocities,

— thermal shock, and

— differential heating

are not reproduced. In a jet fire, the fire protection products will be subjected to erosive forces, pressure fluctuations and higher heat fluxes. It should be noted that the highest erosive forces are not in the region of highest heat flux. Hence, the results of both tests should be considered together when assessing the performance of a fire protection product or material in a range of scenarios. However, in combining results, it is not valid to compare mean substrate temperature from a furnace test with a mean substrate temperature from a jet fire because of the non-uniformity of the heating in the jet fire test.

9.3 Section factor

In principle, the ability of a substrate to absorb heat is generally determined by its section factor (S_f, m^{-1}) or A/V ratio (also known as H_p/A and W/A), i.e. the heated area per unit length (A, m^2) divided by the volume per unit length (V, m^3). Historically,[16] the section factor has been defined in terms of the heated perimeter and area of cross-section but recent standards have used the revised definition given above. However, the units are the same. A substrate with a large mass and small surface area will take a longer time to reach critical temperature than one with a small mass and large surface area. Hence, in furnace tests, it is usual to vary the duration, section factor and fire protection product thickness in order to provide an estimate of the thickness required in a range of situations. The appropriateness, or otherwise, of using the section factor has not been established for jet fire testing and, currently, it is recommended to use a test specimen with a substrate thickness comparable with the practical application.

9.4 Thickness of fire protection material

In general, it is too expensive to test all the practical combinations of substrate thickness, section factor, duration, etc. required, and hence methods are required to predict the thickness of fire protection product or material required.

The most common method used to provide data applicable to a range of situations is that developed for “fire protection for structural steel in buildings” by the Association for Specialist Fire Protection.[16] This is based on the performance of a series of furnace tests conducted on structural elements with varying section factors, usually between 50 m^{-1} and 350 m^{-1}, to various fire durations ($t_{resistance}$) and limiting temperatures. The thickness of material (w, mm) required to provide specific standards of fire resistance are derived by means of the empirical relationship:

$$t_{resistance} = k_0 + k_1 \frac{w}{S_f} + k_2 w \qquad (1)$$

The furnace tests are chosen to cover the range of section factors, thicknesses and durations required. The constants, k_0, k_1 and k_2, applicable to each material are determined by multiple linear regression. With many fire protection materials, it is possible to achieve a coefficient of determination (the square of the correlation coefficient) in excess of 0,95, which indicates a high level of agreement between test and predicted data. If the coefficient of determination is found to be less than 0,95 , then further investigations should be carried out to determine the reasons for the discrepancy and an appropriate safety factor may be included in the analysis to compensate for the variation. Once a satisfactory correlation has been