# 1. Introduction

In facilities where low temperature liquids (such as Liquified Natural Gas (LNG) facilities ) are handled, there is the risk that an accidental leak of liquid could cause embrittlement of the substrate, leading to its failure and the potential escalation of the incident. This occurs if the cryogenic liquid release is capable of reducing the temperature in the substrate below the ductile brittle transition temperature (DBTT).

To prevent failures due to embrittlement, Cryogenic Spill Protection (CSP) may be specified to protect safety and environmentally critical elements. The design of CSP requires matching up appropriate testing against a pre-determined duration and an allowable temperature drop limit.

The test standard ISO 20088 was developed to address typical LNG release scenarios, using liquid nitrogen as the cryogenic medium. Liquid nitrogen was chosen as a more inherently safe cryogenic liquid, which had a boiling point at atmospheric pressure lower than LNG. Using ISO 20088 to represent other cryogenic liquids needs to be appropriately validated.

# 2. This Guidance

This guidance describes the minimum information required to be provided to the CSP system manufacturer to allow them to specify the correct type and thickness of CSP required, based on the ISO 20088 test data. It should be noted that even slight changes in these variables can have a significant impact on the design and cost of the CSP.

It also considers the approach to be taken where the cryogenic spill protection system also provides some other mitigation, such as process insulation, acoustic insulation or passive fire protection (PFP).

Whilst allowable temperature drop ($\Delta T_{drop}$) is a key factor in determining CSP thickness, providing the information on the credible initial temperature for release scenarios ($T_{start}$), and the limiting steel temperature ($T_{critical}$) will assist in understanding that the needs of the project are correctly married against liquid cryogenic exposure test data.

Section 4 provides “key information requirements “, with brief descriptions.

Section 5 provides a pro-forma enquiry sheet that follows the format of the “key information requirements” table given in Section 4. When completing the enquiry sheet, information should be provided for all items that are to be protected against the cryogenic spill, and where necessary the full range of section sizes or plate thicknesses should be provided.

Explanatory Notes for all key information requirements are given in Appendix A.

# 3. Scope

The scope of this guidance covers:

- The use of CSP systems to protect structural components, barriers, process plant and pipework, and critical process control equipment such as valves.
- CSP systems that take the form of wet-applied coating systems (epoxy, phenolic, cementitious) and dry-fit insulation systems.
- Systems that might also provide other mitigative functions in addition to cryogenic spill protection (such as process insulation, acoustic or passive fire protection).

# 4. Key Information Requirements for the Specification of CSP Systems

| Sec | Requirement | Purpose / Commentary |
|---|---|---|
| 1 | Applicable part of the ISO 20088 standard to be used | The correct part of the standard should be selected to represent the type of cryogenic release experienced by the item to be protected.<br>• Part 1: Liquid Spill – **Liquid pool** that forms on horizontal surfaces.<br>• Part 2: Vapour Release – Exposure of a substrate to a pressurised cryogenic liquid jet where vaporisation of the liquid is almost complete (liquid content is minimal).<br>• Part 3: Jet Release – Exposure of a substrate to a pressurized cryogenic **liquid** jet only (gaseous content is minimal). |
| 2 | Type of item being protected | The type of item to be protected should be identified, because:<br>• This is an additional consideration when selecting which part of ISO 20088 to use.<br>• The shape and configuration of the item being protected will strongly influence the required thickness of CSP needed to provide the necessary cryogenic protection. |
| 3 | Item size and shape | Heavier items will cool down less quickly than lighter items, and may require lower thickness of insulation. Therefore the following key information is required:<br>• For steel plate, the plate thickness.<br>• For steel sections, the section factor (Hp/A; A/V; W/D or A/P).<br>• For pipework, a pipe schedule enabling calculation of a section factor.<br>• For items of equipment such as valves, the size, weight and materials information enable the calculation of an equivalent thermal mass. |
| 4 | Credible start temperature ($T_{start}$) for release scenarios | 4a substrate at ambient temperature: When the substrate is at the same temperature as the credible ambient temperature at the facility when the cryogenic liquid is released then this value is used as $T_{start}$ in the calculation of allowable temperature drop. |
| | | 4b substrate at process temperature: When substrate operates at very high or very low in-service temperatures (for example thermal insulation for process pipework), then the value of $T_{start}$ should be taken as the in-service temperature of the substrate. |
| 5 | Limiting item temperature ($T_{critical}$) | The lowest temperature that the item is allowed to reach during the cryogenic release exposure duration. For example, steel is susceptible to fracture at temperatures below the DBTT, and the limiting temperature should be specifically determined based on the material grade used. |
| 6 | Allowable temperature drop ($\Delta T_{drop}$) | The difference between the credible ambient temperature ($T_{start}$) and the limiting item temperature below which the temperature of the item should not drop ($T_{critical}$). This is a key variable in the determination of CSP thickness. |
| 7 | Cryogenic protection duration (mins) | The duration of exposure of the cryogenic spill over which the cold temperature effects must be mitigated to prevent the limiting item temperature being reached is required for the calculation of CSP thickness. |
| 8 | Other hazard mitigation requirements | If the CSP system also mitigates other hazards such passive fire protection (PFP), hot or cold insulation, or acoustic insulation then the requirements and any ratings that describe these hazards should be provided to ensure that they are integrated with the CSP requirement. |

## 5. Enquiry Sheet for the Specification of CSP Systems

<table>
<tr><th>Sec</th><th>Requirement</th><th colspan="2">Response</th></tr>
<tr><td>1</td><td>Applicable part of the ISO 20088 standard to be used.</td><td colspan="2"></td></tr>
<tr><td>2</td><td>Type of item being protected</td><td colspan="2"></td></tr>
<tr><td>3</td><td>Item size and shape</td><td colspan="2"></td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Credible start temperature of the substrate ($T_{start}$) for release scenarios</td><td>4a substrate at ambient temperature</td><td></td></tr>
<tr><td>4b substrate at process temperature</td><td>define process conditions</td></tr>
<tr><td>5</td><td>Limiting item temperature ($T_{critical}$)</td><td colspan="2"></td></tr>
<tr><td>6</td><td>Allowable temperature drop ($\Delta T_{drop}$)</td><td colspan="2"></td></tr>
<tr><td>7</td><td>Cryogenic protection duration (minutes)</td><td colspan="2"></td></tr>
<tr><td>8</td><td>Other hazard mitigation requirements</td><td colspan="2"></td></tr>
</table>

 

# Appendix A - Explanatory Notes

## Acronyms & Definitions

| Acronym | Meaning |
|---|---|
| CSP | Cryogenic Spill Protection |
| DBTT | Ductile Brittle Transition Temperature |
| Hp/A, W/D, A/P, or A/V | Section Factor |
| ISO | International Standards Organisation |
| LNG | Liquified Natural Gas |
| LIN | Liquified Nitrogen Gas |
| PFP | Passive Fire Protection ("Fireproofing") |
| $T_{critical}$ | The design limit for the steel to prevent brittle failure |
| $T_{start}$ | Temperature of the substrate expected when cryogenic spill occurs |
| $\Delta T_{drop}$ | The difference between $T_{start}$ and $T_{critical}$ |

### Section 1: Applicable part of the ISO 20088 standard to be used

ISO 20088 has 3 parts that consider different forms of cryogenic release that may occur. The standard subjects the CSP systems to a prescribed test protocol to establish their ability to mitigate low temperature effects of a simulated cryogenic spill on the steel they protect. The test monitors the drop in temperature experienced by a protected substrate from the initial ambient temperature at the test site, over a prescribed duration when exposed to cryogenic liquid nitrogen (LIN) releases.

Selecting the correct type of cryogenic spill is important because it influences the required thickness of CSP to manage the allowable temperature drop. For a given duration of exposure, the required thickness of CSP generally increases as the phase changes from vapour to spray/jet to immersion/ponding.

As well as the influence of the release conditions, a consideration of the actual item which is exposed to the cryogenic liquid will also guide the selection of the correct part of ISO 20088 to be used. In general:

- Part 1 is normally specified for protection of horizontal surfaces such as decks or bunds where large pools of cryogenic liquid could accumulate.
- Part 2 is rarely specified in the LNG sector as vapour is assumed not to cool the steel sufficiently in open, ventilated areas.
- Part 3 is generally used specifically where no liquids will accumulate, such as for open and closed structural steel beam and column sections, vessel supports, vessels, process equipment such as valves, and pipework.

The appropriate test for CSP applied to vertical divisions is discussed in Section 2.

### Section 2: Type of item being protected

The type of item being protected will influence both the test to be undertaken (as noted above) but also the thickness of CSP material that must be applied to manage the temperature drop requirements. The following type of item should be identified:

- Open sections (I-Sections, wide flange beams, channels, etc).
- Closed or hollow sections (Structural columns, bracing, pipes, etc).

- Horizontal or vertical divisions.
- Pipework or process vessel.
- Any control equipment such as valves.

Distinction between the types of items to be protected is important because:

- Hollow sections and divisions generally require more protection than I sections because the geometry of I sections provides shielding from the effects of the cryogenic jet releases.
- ISO 20088 does not expose a vertical division to a cryogenic liquid jet release.
- I-section data should not be used for other shapes such as divisions, hollow sections and vessels/tanks. Vertical divisions can be considered as directly tested against a vapour release as defined in part 2 of ISO 20088. I-sections and hollows sections are not specified as test pieces for part 2 of ISO 20088 as geometry was not considered a significant variable for gaseous exposure.
- CHS data may be used for all sections with this closed geometry (e.g. pipework, structural steel columns, bracing etc.) and for divisions exposed to cryogenic jet release (resulting in no accumulation of cryogenic liquid) where a correlation has been shown between part 1 test geometry and part 3 CHS test geometries with an equivalent section factor.
- Valves are represented using heavy circular hollow sections, or circular hollow section with a dummy valve represented by an additional pipe with a heavy section factor. Use of I-section data is not appropriate.

## Section 3: Item shape and size

Heavier/thicker items (often manufactured from steel) have a greater thermal mass and will cool down more slowly resulting in less CSP material being required to a mitigate a specified temperature drop and exposure duration. However, when considering brittle fracture performance of welded steel structures then, depending on the structural detail and other credible accidental release outcomes (e.g. resilience to blast or projectile), thinner welded steel can be less susceptible to brittle fracture, which has the potential to permit a greater drop in temperature.

Knowledge of the size of the item to be protected is required to enable the correct thickness of CSP to be supplied for an allowable temperature drop:

- For steel plate structures, the thickness of the plate is required.
- For structural sections, the section factor is required.
- For pipework, the pipe schedule enabling calculation of a section factor is required.
- For items of equipment such as valves, the size, weight and materials information (typically found on a GA datasheet) is required enable the calculation of an equivalent thermal mass.

For structural sections, the sections exposed to cryogenic spill may be described by the section factor (one of Hp/A; A/V; W/D or A/P depending on geographical location). This nomenclature is also used for sections exposed to fire. These ratios can represent a range of different section sizes that exhibit the same thermal response (to both high and low temperatures). Furthermore, “bands” of section factor can simplify designs and the specification of both CSP and PFP by grouping sections together an applying a limited range of CSP thickness, rather than a wide range of different thicknesses on a member-by-member basis across a facility.

Care is required with section factor for tubular sections. The outer diameter to inner diameter ratio drives heat transfer and this could differ for items with the same section factor.

Typically as section factor increases, more CSP material is required (although not in the case of W/D as this is an inverse relationship).

## Section 4: Credible start temperature ($T_{start}$)

The credible start temperature describes the temperature of the substrate at the moment that the cryogenic material is released onto it. Selection of a credible start temperature ($T_{start}$) is a critical factor in determining CSP thickness.

CSP systems will typically experience two possible sources of start temperatures for the substrate which are defined by the function of the CSP material:

- The temperature of the substrate is determined by the credible ***ambient*** temperature of the site (for example – structural steel), or;
- The temperature of the substrate is determined by ***operational/process*** temperatures which could be higher or lower than ambient temperatures (for example – process pipework.)

With respect to ambient temperatures, the lowest or highest expected ambient temperature at the site over its design life is not normally used as basis of CSP design as the likelihood of a cryogenic spill occurring at the same time as the lowest expected ambient temperature is not considered a credible event. As an example, a more credible ambient temperature in this case would be the average temperature for the coldest month of the year or alternatively may be determined at the discretion of the design engineer aligned with owner expectations.

Generally if the credible start temperature (ambient or process) is lower than the steel temperature used for the ISO 20088 testing (23°C +/- 3°C), then the insulation solution required may be taken as sufficiently conservative for a given temperature drop. This is because for passive insulation systems the thermal conductivity reduces with temperature, even at cryogenic temperatures, so the thickness is lower than that predicted from the ISO 20088 test starting at 23°C +/- 3°C . At very low temperatures, the temperature drop, $T_{drop}$, before the limiting steel temperature is reached is likely to be small and the thickness of insulation needed to manage this small temperature drop over the exposure duration will be high.

If the cryogenic spill subsequently occurs at a higher start temperature (ambient or process), the drop in temperature to reach the limiting temperature will be larger, meaning that less CSP material is needed to manage this situation over the exposure duration.

Care has to be taken if the ambient temperature is greater than the steel temperature used for the ISO 20088 testing. Whilst it may be considered "optimal" to select a high start temperature to minimise insulation thickness, should the prevailing start temperature actually be lower during any cryogenic release, the thickness will be under-specified for the smaller allowable temperature drop and the limiting temperature may be reached before the end of the exposure duration.

As well as insulation performance, higher start temperature can also affect the integrity of reactive CSP systems. This is because the sudden exposure of a warm CSP system to the cryogenic spill can result in a greater thermal shock, and this effect is not captured in the ISO 20088 test with a start temperature of 23°C +/- 3°C. The resulting insulation performance might be inferior than expected.

Advice should be sought from the manufacturer on any specific validation to reflect low and high start temperature effects, and also how these temperatures may affect the long term CSP system durability over the operational lifetime.

## Section 5: Limiting item temperature ($T_{critical}$)

When exposed to low temperatures, a material such as steel transitions from ductile behaviour to brittle behaviour. Different grades of steel, steel thickness, and details affect the temperature at which this change in behaviour occurs. This temperature is the Ductile to Brittle Transition Temperature (DBTT) and governs fracture and notch toughness behaviour of the steel. Using CSP delays this limit being reached and prevents loss of integrity of the structure or equipment item from occurring.

In a project specification the critical temperature below which the item is not permitted to be reached ($T_{critical}$), is a key variable required when considering CSP specification. It may be based on a range of factors, not just the exact DBTT, and may vary from item to item depending on material and other considerations (e.g. defects at welds may initiate cracking at higher limiting temperatures).

Limiting steel temperature is used to calculate the allowable temperature drop ($T_{drop}$).

## Section 6: Allowable temperature drop ($T_{drop}$).

The allowable temperature drop is calculated by:

$$\Delta T_{drop} = T_{start} - T_{critical}$$

Allowable temperature drop has a significant impact on the thickness of CSP required, and the use of CSP should be balanced with using alternative grades of substrate material with better low temperature performance – which may be more cost effective.

When testing to the ISO 20088 standard, the temperature of the specimen ($T_{start}$) is fixed at 23°C +/- 3°C, unless otherwise agreed. At the actual cryogenic facility, the substrate temperature may be significantly lower (e.g. ambient air temperature) or significantly higher (e.g. in-service process temperatures) than this test temperature. The results of the CSP system's insulation performance obtained from the relevant ISO 20088 test are therefore adapted to meet the needs of a specific project design requirement. Adaption techniques are required to be validated against test data.

## Section 7: Cryogenic protection duration

The CSP system will be required to manage the temperature drop over a defined duration of exposure to the cryogenic hazard so that the risks to people the asset and the environment as a result of a failure are managed to a level that is as low as reasonably practical. Risk assessments are used to identify this duration through consideration of a number of factors, such as emergency response and evacuation.

Alternatively, a prescriptive approach may be adopted for a facility as the means of identifying the duration. For example, the duration could be set at 10 minutes based on NFPA 59A- 2019 guidance (Section N.5.3.2.4).

## Section 8: CSP and mitigation of other hazards

There is complexity when the material that provides cryogenic spill protection is also required to provide some other mitigation such as process insulation, acoustic insulation or passive fire protection (PFP). The CSP system may be able to mitigate a combination of these hazards, or the CSP element is provided by a part of a multi-layered system with different layers protecting against different hazards. Typical dual combinations are CSP + PFP, and CSP + process insulation. In some instances the installed system might be required to provide all four mitigations.

In this instance, calculation to determine the required thickness to mitigate each hazard will be undertaken, and the greatest thickness of insulative material should be specified. The most onerous reinforcement, mechanical fixings or details to mitigate the most severe hazard (usually either cryogenic spill or fire) should also be specified for the combined system.

A specific consideration is the case where mitigation for CSP+PFP is required. Here the calculation for the thickness of PFP required to satisfy the classification temperature for the fire should not take any credit for lower substrate temperatures that may be present at the start of fire testing that immediately follows the ISO 20088 cryogenic test, and the classification temperature is based on an allowable temperature rise rather than an absolute temperature not being exceeded. As an example, calculation of jet fire erosion factors for PFP coatings after a cryogenic liquid exposure are calculated using the temperature rise from the actual start temperature after cryogenic exposure and compared to the equivalent temperature rise in the absence of cryogenic exposure.