gas as a marine fuel

Work practices for maintenance, repair and dry-dock operations

safety

version 1.0

SGMF

the society for gas as a marine fuel


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This book is dedicated to the memory of Marcel LaRoche who, while at British Columbia Ferries, pioneered many of the basic tenets of this new industry.

His contribution to the early stages of this group was very important in giving this publication its form and direction, his guidance was sorely missed during the later stages.
Firstly it was an honour and a privilege to chair this particular working group. The quality, experience and technical knowledge of the team contributed in developing this new guidance for dry-docking vessels which select to use methane gas as a fuel from LNG storage facilities on board the vessel.

With more focus on the environment and addressing emissions the marine industry has embraced the challenge under direction of the International Maritime Organization (IMO) to tackle emissions. The IMO has enforced a new 0.5% global sulphur cap on fuel. MARPOL Annex VI Regulation 14 limits the fuel oil sulphur content to any fuel oil used onboard all ships, new and existing, to 0.50% m/m as of 1 January 2020.

This is a strong move towards reducing harmful emissions from vessels of all types which forces the maritime industry to look for more efficient environmentally suitable fuels that comply with the new IMO legislations. Hence why gas as a marine fuel is part of the emissions solution.

Shipping companies who undertake the use of LNG storage and gas as a marine fuel will need to be ready for first dry dock. This guidance will provide the required detail and direction to the ship owner in selecting the prequalified yards and the yards will be able to use the guidance to prepare and be LNG ready.

The guidance offers a risk assessment approach and covers all aspects of LNG fuel management while preparing for the docking and during the docking process.

LNG as a marine fuel will continue to grow and more vessels will switch to gas as the preferred fuel to meet the IMO legislation on emissions. It is important that prior to any docking both vessel and yard fully understand the preparation and the fuel management during the docking period. This guidance will give the majority of detail, but it is advised to fully understand the LNG handling methodology and appoint an LNG specialist within the fleet and the yard.
It only remains for me to thank the SGMF and the participants of the working group whose efforts and time was shared to put this guidance together.

Thank you.

Andrew Brown
Smit Lamnalco
Chairman, SGMF WG10
Abbreviations and Definitions

**ALARP/ALARA** – As Low as Reasonably Practicable/Achievable without incurring excessive cost

**Asphyxia** – a condition arising when the body is deprived of oxygen that may result in impairment and ultimately death

**Asphyxiant** – a gas that displaces or replaces oxygen in the atmosphere, thus posing the threat of asphyxiation – for example, nitrogen and methane vapour

**ATEX** – Appareils destinés à être utilisés en ATmosphères EXplosibles. (Equipment destined for use in potentially explosive atmospheres.) The European Union ATEX Directive 2014/34/EU covers equipment and protective systems intended for use in potentially explosive atmospheres

**bara/barg** – pressure stated as absolute/gauge pressure, meaning the pressure zero-referenced to that of a perfect vacuum or ambient atmospheric pressure

**BOG** – Boil-Off Gas. The vapour created by evaporation from the surface of a volume of LNG

**Chemist** – a skilled and qualified person who works with chemicals to define their behaviours and reactions and their effects on humanity and the environment

**Class(ification) Society** – an organisation that establishes and maintains technical standards for construction and ongoing operations to ensure the safety of ships

**CNG** – Compressed Natural Gas is natural gas stored at high pressure (up to 300 bar)

**CO₂** – carbon dioxide, a combustion product and a major greenhouse gas

**Competence** – the capability to undertake a task and complete it successfully with confidence and understanding

**Competent Authority** – any national, regional or local authority empowered, alone or together with other authorities, to act as the regulatory body on the use of LNG onboard ships

**Cryogenic** – temperatures below -101°C (NFPA)

**Dew Point** – the temperature, at a specified pressure, at which a vapour condenses its first drop
of liquid and will continue to condense if cooled further

**Dry air** – air, at atmospheric pressure, with a dew point of -70°C (about -100°F) and containing less than 2.6 parts per million of water by volume

**EN** – European (Standard) Norm

**ESD** – Emergency Shut-Down, a control system and associated components that, when activated, stop operations in a controlled manner, returning a system to a safe state

**ESSF** – European Sustainable Shipping Forum, an EU consultative body for LNG as a marine fuel

**EU** – European Union, a political and economic alliance of 27 countries in Europe

**EX** – equipment classified as safe to operate in hazardous areas where a flammable gas may be present

**Flag (state)** – the place where a vessel is registered and whose rules a ship must be operated to. The rules are normally the interpretation of IMO regulations which can be implemented directly or via Class Societies

**GaN** – Gaseous nitrogen

**Gas** – a fluid above its critical point that cannot be turned into a liquid by pressure alone

**Gas Doctor** – see Chemist

**Gas free** – when a vessel, container or area has concentrations of flammable gases below a prescribed limit.

**Gassed up** – a piece of equipment or pipework where a flammable gas is or may be present. By extension, where a liquid such as LNG is present which may vaporise to create a flammable gas

**GCU** – Gas Combustion Unit, a way of disposing of methane and other hydrocarbons by catalytically burning them into CO₂ and water

**Hazardous area/zone** – the three-dimensional space in which a combustible or explosive atmosphere can be expected to be present frequently enough to require special precautions for the control of potential ignition sources. Defined by national regulations and both the IGF and IGC codes
Abbreviations and Definitions

**HAZID** – HAZard IDentification. There are a number of recognised methods for the formal identification of hazards. For example, a brainstorming exercise using checklists where the potential hazards in an operation are identified and gathered in a risk register to be addressed and managed.

**HAZOP** – HAZard and OPerability study, a safety process that reviews how systems react to changes in their operating parameters that may cause additional hazards.

**HSEQ** – Health, Safety, Environment and Quality

**IACS** – International Association of Classification Societies, a technically based non-governmental organisation that consists of the 12 main Classification Societies aiming to produce consistent standards for marine ships.

**IAPH** – International Association of Ports and Harbours, the global trade association for ports and harbours.

**ICS** – International Chamber of Shipping, the international trade association of merchant ship owners and operators including all ship types.

**IGF** – The International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels

**IMO** – The International Maritime Organization. The United Nation’s maritime regulatory body.

**ISGOTT** – International Safety Guide for Oil Tankers and Terminals, published jointly by IAPH, ICS and OCIMF.

**ISM** – The International Safety Management Code published by the IMO.

**ISO** – The International Organization for Standardization. An international standard-setting body composed of representatives from various national standards organizations.

**ISPS** – IMO’s International Ship and Port Security Code, describing minimum security requirements for the maritime sector.

**LFL** – Lower Flammable Limit. The low end of the concentration range over which a flammable mixture of gas and vapour in air can ignite at a given temperature and pressure.
LIN – Liquid nitrogen, normally below -196°C at ambient conditions. Also known as LN2

LNG – Liquefied Natural Gas. Natural gas in a liquid state. GNL in French, Spanish and Italian (the French is Gaz Naturel Liquefié)

LNG-ready dry-dock – A shipyard that has plans, skills, equipment and management systems in place to handle competently gas/LNG-fuelled vessels with fuel (gas/LNG) onboard during maintenance

LPG – Liquid Petroleum Gas, a mixture of propane and butane used as fuel and chemical feedstock

LSHFO – Low-Sulphur Heavy Fuel Oil, a residual fuel oil whose sulphur content is below 0.5%

Maintainer – members of the vessel’s crew, a shipyard and any subcontractors/OEMs employed by the owner or the yard to perform maintenance or repair work

MAP – the Maximum Acceptable Pressure allowed by competent authorities as part of a gas-management plan. The MAP will be an agreed percentage of the MARVS

MARVS – Maximum Allowable Relief Valve Setting, the pressure at which a relief valve used to protect a pressurised system opens to control and reduce pressure

MGO – Marine Gas Oil

Natural gas (NG) – A mixture of hydrocarbon gases, mostly methane, used as a fuel or chemical feedstock. Also used to refer to regasified LNG

NDT/NDE – Non Destructive Testing/Examination, techniques that allow a system or component to be examined and proven without damage

NFPA – The National Fire Protection Association, a US-based standards body for fire, electrical and related hazards

OCIMF – The Oil Companies International Marine Forum, an association representing operators of oil tankers and terminals, dealing with safety and environmental issues and specifically associated with mooring and berthing guidelines

OEM – Original Equipment Manufacturer
Abbreviations and Definitions

**ORA (Operational Risk Assessment)** – Risk assessments resulting from operations and maintenance activities to ensure levels of safety are not compromised while activities continue

**PPE** – Personal Protective Equipment

**ppm** – parts per million, a measure of concentration

**PRV (Pressure-Relief Valve)** – a mechanical device used to prevent pressure rising above a predetermined level

**QRA** – Quantitative Risk Assessment, a formalised, numerical risk assessment methodology for calculating a risk level for comparison with defined risk criteria

**QSHE** – see HSEQ

**Risk** – A combination of the likelihood of an event occurring and the consequences of the event occurring

**Risk Assessment** – a term used to describe the overall process or method whereby hazards and risk factors that have the potential to cause harm are identified, analysed and evaluated so that appropriate mitigations – both physical and managerial – can be put in place to reduce risks to acceptable levels

**RPT** – Rapid Phase Transition, the rapid – potentially explosive – vaporisation of LNG into vapour through contact with a heat source, typically water

**Safety-Sensitive Area** – Locations where heightened work control is required because they border on hazardous areas or include systems essential to safe vessel operation

**SBTT** – Secondary Barrier Tightness Test, a process whereby the continuing integrity of a (GTT) membrane type fuel tank is assured

**SGMF** – The Society for Gas as a Marine Fuel, an international organisation providing guidance on the safe and responsible use of low-flashpoint fuels in a marine context

**Shipyard** – a controlled area where ships are built and repaired

**SIGTTO** – The Society of International Gas Tanker
and Terminal Operators, an organisation representing operators of gas tankers and import and export terminals, covering all liquefied gases in bulk

**SIMOP** – **SI**multaneous OPeration. Defined in this document as “an activity where LNG or its vapour is transferred or has the potential to escape containment plus one, or more, other activity and/or operation conducted at the same time where their interaction may adversely impact safety, ship integrity and/or the environment”

**Special steel** – a steel not typically used for a vessel hull and structures such as a high alloy steel, for example stainless steel (or an alternative material such as aluminium) required to contain LNG and gaseous fuels.

**STCW** – Standards of Training

Certification and Watchkeeping, an IMO publication detailing standards and training for mariners on different ship types

**Training** – the teaching of a particular skill or method of doing something

**TRV (Thermal-Relief Valve)** – used to relieve pressure caused by the thermal expansion of process fluids in vessels and lengths of pipework

**ULSHFO** – Ultra Low Sulphur Heavy Fuel Oil, a residual fuel oil with a sulphur content below 0.1%

**Vapour** – a fluid which appears to be a gas but can be turned into a liquid by a change of pressure

**VIT** – Vacuum-Insulated Tank, a Type C tank with a vacuum jacket for insulation
While this document is specifically about LNG, much of the discussion applies to other fuels allowed by the IGF Code. However, each fuel has its own peculiarities – for example, the cryogenic nature of LNG or the toxic hazard associated with methanol – so this guidance should be used in its entirety only for LNG.

LNG and natural gas behave differently from traditional fuel oils when released into the air or onto water or land. Safety precautions should be assessed differently than for traditional maintenance operations. This guide explains how to assess these differences.

This publication is a technical book which primarily provides the necessary information for individuals and organisations to start developing maintenance and safety guidance. It does not provide rules or definitive practices but the framework on which to base more detailed rules and procedures.

Parts of these guidelines talk about the mitigation of LNG/gas hazards. This does not include emergency response (including firefighting). Once a hazardous event has occurred, risk assessments are overtaken by emergency service protocols. Guidance for the emergency services is being developed or has been covered elsewhere by other industry bodies (such as SIGTTO, CCNR and OPITO).

These guidelines do not address the following:

- equipment-specific maintenance required by certain equipment models, OEMs or manufacturers/vendors
- maintenance frequencies required by OEMs, Class Societies or Flag states
- the commercial impacts of maintenance activities

It is up to the ship-owner, yard, and/or competent authority to assess each situation and, if necessary, to apply alternative measures.

While the advice given in this Guide is based on current good industry
practices and available information, it is intended solely for guidance and use at the owner’s/operator’s/Maintainer’s own risk. No responsibility is accepted by SGMF – nor by any person, company or organisation related to SGMF – for any consequences resulting directly or indirectly from compliance with, or adoption of, any of the recommendations or guidance contained herein.
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1. Purpose and Scope

1.1. Aim
This document provides guidance on how to maintain vessels using LNG/gas as fuel. Maintenance covers all the activities that keep a vessel operating safely to its specifications. It can range from maintenance by a ship’s crew through to major repairs and inspections requiring a dry dock. The guidance concerns techniques and precautions that can be applied to minimise the hazards of LNG/gaseous fuels – in many cases, allowing the use of traditional maintenance techniques. Where this is not possible, the guidance discusses alternative methods.

These guidelines were created collaboratively by industry members of the SGMF. The guidance assumes that gas-fuelled vessels are designed according to relevant and applicable codes, regulations and guidelines.

These guidelines emphasise and advise some new concepts. These include:

- LNG remaining on board a vessel during maintenance may become the norm – requiring additional risk assessment and precautions.
- where there is a risk that gas may be present, a technique called hazardous areas classification is used as one mitigation.
- this guidance also defines a “safety-sensitive area“ where enhanced safety performance is required. Safety-sensitive areas are locations that border on hazardous areas or include systems essential to safe vessel operation and where heightened work control is required.
- safe systems of work – both procedures and methods of working – are essential within hazardous zones and safety-sensitive areas to preserve the integrity of these locations, even if the LNG system itself is not being maintained.
- a “LNG-ready dry dock“ will have developed systems of safe working and the necessary procedures which have been approved by the appropriate regulators.

Minimum safety requirements are defined by International, national and/or local regulating bodies. Competent authorities will define procedures for compliance and enforce the regulations. This guidance will assist in streamlining and standardising these procedures.
2. Maintenance of LNG/Gas-Fuelled Ships

Vessel reliability depends on design, construction, initial commissioning, operating practices and timely completion of required maintenance. For installed equipment, the execution of appropriate maintenance procedures is essential to ensure vessels are operated safely and reliably, and to eliminate unnecessary downtime or incidents.

Maintenance takes several forms:

- planned maintenance in service
- planned maintenance and repairs out of service
- unplanned maintenance and repairs

These scenarios apply to all types of vessel, gas or conventionally fuelled. In the context of this guidance, they are defined as follows:

<table>
<thead>
<tr>
<th>Maintenance/repair type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned maintenance in service</td>
<td>Ongoing and daily routine maintenance while the vessel remains on hire.</td>
</tr>
<tr>
<td>Planned maintenance and repairs out of</td>
<td>Maintenance and inspection at anchor, alongside, in a dry dock or vessel repair facility, with the vessel off-hire.</td>
</tr>
<tr>
<td>service</td>
<td></td>
</tr>
<tr>
<td>Unplanned maintenance and repairs</td>
<td>Unexpected or unforeseen circumstances where a vessel requires maintenance or repair. Vessel may be in service or off-hire, depending on the initiating event.</td>
</tr>
</tbody>
</table>

To allow maintenance to take place on board gas-fuelled vessels using normal shipyard practices and without the need for any additional risk assessments or modification of competent authority licences, all fuel is often removed from a vessel before it enters the shipyard. This fuel removal process has implications for:
• safety – LNG/gas needs to be removed from the vessel before maintenance work begins and then replaced afterwards.

• the environment – the gas atmosphere must be removed from the tank/pipework/equipment, either through venting to the atmosphere or controlled combustion, both resulting in additional greenhouse gas emissions.

• reliability – additional thermal/pressure cycles need to be performed, reducing remaining fatigue life and the life of gas-tight seals. Moreover, insulation may need to broken and reinstated.

This guidance covers the additional processes and procedures that need to be performed to achieve a similar level of safety even if gas or LNG remains present on board the vessel during maintenance work. Of primary importance is the potential for a leak of gas or LNG to affect the immediate area and/or surrounding areas of the vessel or the shipyard. The removal of gas and its reinstatement have negative environmental implications and may impact equipment integrity and lifetimes.

In general, there are three scenarios to consider when maintaining a gas/LNG-fuelled ship:

1. All of the vessel’s systems contain LNG or natural gas (gassed up and cold):
   - fuel storage, processing and supply system equipment – for example, BOG compressors – may be maintained using special procedures such as selective isolation from gas-containing systems and purging
   - systems outside of the fuel storage, processing and supply systems can be maintained after additional risk assessment. Clear identification of the work area is essential and safety systems that work vessel-wide should not be compromised by localised maintenance work. Cryogenic methodologies and good housekeeping practices should be followed.
   - equipment located in areas where fuel is unable to enter because of their distance from fuel systems or because of
air locks, gas-tight bulkheads and so on – typically including the accommodation, passenger and cargo spaces – can be maintained as normal provided that other maintenance activities do not allow gas to reach these areas. Most maintenance is in this category.

2. Parts of the vessel’s systems contain LNG or natural gas:

- the systems that require maintenance should be freed of gas. As a gas hazard maybe present elsewhere on the vessel, safety precautions must reflect this. Clear identification of the work area is essential and safety systems that work vessel-wide should not be compromised by the localised maintenance work. Cryogenic methodologies and good housekeeping practices should be followed.

- the absence of a flammable gas should be confirmed by continuous monitoring throughout the duration of the maintenance work.

- an example of this condition is where multiple LNG tanks are available; LNG can then be transferred from one tank to another and the empty tank isolated and purged for access.

- Note: to achieve a gas free condition, a vessel may have spaces that are under nitrogen, which represent an asphyxiation hazard, or remain at cryogenic temperatures.

3. None of the vessel’s systems contain LNG fuel or natural gas:

- If the vessel is completely cleared of fuel and its vapour, normal maintenance practices with conventional safety systems are allowed. However, the special steels and cryogenic nature of the vessel will still impose restrictions on working methods and housekeeping.

- The decision to completely free a vessel of gas is a significant one – discussed at length in Section 8. If there is only one LNG tank and it needs to be entered for inspection or for maintenance and/or the replacement of equipment, such as fixed in-tank fuel pumps, then gas-freeing is unavoidable.
Note: To achieve a gas free condition, a vessel may have spaces that are under nitrogen, which represent an asphyxiation hazard. (These spaces may be under nitrogen to prevent the potential build-up of a flammable atmosphere during normal operations and/or to preserve key items of equipment during maintenance.)

These three scenarios are described in the flowchart in Figure 2.1.

Even if a vessel is described as gas-free, this should not be relied upon without checking. When the vessel arrives, gas samples should be taken from multiple locations to confirm that gas freeing has been performed correctly.
Figure 2.1: Maintenance scenarios for LNG/gas-fuelled vessels

**Option 3: Vessel remains gassed up**
- Implement gas pressure management plan
- Isolate gas systems required for maintenance
- Impose access restrictions to gas-live areas
- Implement good housekeeping and additional risk assessment
- Maintain systems using special maintenance practices
- Reinstate system after maintenance

**Option 2: Partially gas-free vessel**
- Implement gas pressure management plan
- Identify hazardous zones and safety-sensitive areas
- Impose access restrictions to gas-live areas
- Implement good housekeeping and additional risk assessment
- Where is maintenance required?
  - Within hazardous or safety-sensitive areas
    - Maintain system(s) using special maintenance practices
    - Reinstate system after maintenance
  - Distant from hazardous or safety sensitive areas
    - Normal maintenance practices

**Option 1: Completely gas-free vessel**
- Remove fuel
- Purge to gas free vessel and warm up tanks
- Oxygenate tank and monitor atmosphere
- Implement good housekeeping and additional risk assessment
- Reinstate systems/tank after maintenance

**Maintenance with gas-live systems**

Where is maintenance required?
- Within hazardous or safety-sensitive areas
- Distant from hazardous or safety sensitive areas

End
Implement gas pressure-management plan
If gas remains within the fuel tanks, the pressure of the tank must be maintained below its maximum operating pressure to avoid venting gas. Gas pressure-management plans are described in Section 5.3.1.

Identify hazardous zones and safety-sensitive areas
Identify and mark areas where special working precautions are required, as described in Sections 3.3 and 3.4.

Isolate gas systems
Seal the system to be maintained by closing the appropriate valves to stop LNG or natural gas vapour entering. Isolation is described in Section 7.1.

Remove fuel
If necessary, remove fuel from parts of the vessel by transfers to other locations on the ship or to external bodies, as described in Section 8.1.1.

Purge, warm up and oxygenate
Remove any LNG and/or natural gas vapour in the system by purging with an inert gas. Once no flammable gas is detected, warm the system up. Purging is described in Section 7.2.

Impose Access restrictions
If LNG and/or vapour is likely to be present in a space, working and entry restrictions are required to limit access to competent individuals – see Section 6.5.

Good housekeeping
Cleanliness and good housekeeping are more important with LNG systems that use special metals, may freeze if moisture gets into them, and where cooling down/warming up takes considerable time. Good housekeeping practices are described more fully in Sections 7.5 and 7.11.

Risk assessment
Risk assessment is described in Section 3.2.

Normal maintenance practices
Practices used for maintenance on conventionally fuelled vessels.

Special maintenance practices
Modified maintenance practices that use special procedures, tools and/or materials. These procedures are described more fully in Sections 6.4 and 7.

Reinstate after maintenance
As a minimum, these processes involve removing air and moisture from the system using an inert gas. Reinstatement can also involve cooling down the system and allowing gas/LNG to enter it. Reinstatement is described in more detail in Section 7.9.
3. Gas Fuel Fundamentals

This document is primarily concerned with the different behaviours and working practices needed to undertake maintenance should LNG be present on board a vessel, either as a liquid (LNG) or as a gas (natural gas).

Two key risks of gaseous fuels are their mobility and invisibility. An oil, when spilled, may flow a limited distance along a deck or down to lower levels of the vessel. Simple structures can stop or divert the flow. The presence of fuel can normally be seen easily and the exact extent of the spill identified. Gaseous fuels have to be contained within completely sealed systems and are colourless (when warm) and odourless.

3.1. How LNG Behaves

Natural gas and the vapour that LNG produces are flammable. This flammability produces energy which is used to power and drive the ship. If this energy leaks or is not effectively controlled, it can damage the ship, harm the environment and injure people.

The safe handling of LNG and natural gas requires a good understanding of some of the physical phenomena associated with the use of LNG as a fuel.

LNG:

- is a boiling liquid which, because of its low storage temperatures (-163 to -130°C, depending on pressure), is continuously vaporising into gas (boil-off gas, or BOG) as it absorbs heat from the environment
- will vaporise and rapidly pressurise a system to bursting point if left trapped between two valves without pressure relief
- will rapidly damage ship-quality steels in the area around a spill; rapid cooling reduces the ductility of steel and its ability to support load, which can cause brittle fracture of a vessel’s deck or of a steel component of a quayside
- may cause a Rapid Phase Transition (RPT) if it is mixed with water and boils so rapidly that an over-pressure situation occurs; an RPT is effectively a flameless explosion
The fuel vapour called BOG (which includes vapour return):

- is heavier than air until it warms to -110°C; so, if it leaks, it will initially flow downwards
- is flammable at concentrations between 5% and 15% in air
- is not odourised and so does not smell like pipeline natural gas
- is not itself visible but causes surrounding water vapour to condense, producing a visible white cloud
- can lead to a lack of visibility within a vapour cloud
- can be cold enough to cause hypothermia, cold burns and frostbite
- may replace oxygen within a vapour cloud preventing people from breathing (asphyxiation)

More detailed descriptions of LNG and natural gas behaviours, covering a wider range of scenarios, are provided in Appendix A.

3.2. Risk Assessment

All vessels and shipyards should have risk identification and management processes for operation of their facilities; ships are covered by the ISM Code and shipyards by onshore legislation, such as health and safety at work and major hazard licences (for example, Seveso III in Europe). These risk assessment and management processes should govern all work during maintenance. The two systems should be examined for suitability during the work tendering process so that an aligned risk management process can be applied when a vessel enters a shipyard. Liquefied gases and gaseous fuels present different hazards when compared with conventional fuels. At this early stage of the development of the LNG-as-fuel industry, risks cannot be directly compared with those associated with long-established conventional fuels. Risk assessment and mitigation needs to have a much higher profile. This is often described as developing a “gas safety culture”.

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SGMF
**Gas Safety Culture**

Gaseous spills or leaks are different from liquid fuel leaks as they:

- can flow upwards or downwards depending on temperature
- can flow (diffuse) through small spaces where oil cannot
- are not visible when warm
- have no odour
- may accumulate in ship spaces with insufficient ventilation
- ignite more easily

The extent and location of a gas release is hard to define and additional precautions are needed to ensure safety. Key among these are:

- gas detection
- ventilation
- containment of gases in high integrity systems (for example, all welded and pipe-in-pipe systems with purging or high ventilation rates)
- spark-free working procedures and tools and equipment designed to be inherently safe
- the ability to isolate the gas supply close to the leak

These precautions are called “barriers”. They are ways of preventing a gas leak from escalating to a more serious event, such as a fire or explosion. Barriers may be passive or active. A passive barrier is always present and does not require anyone or anything to initiate it – for example, insulation or welded construction. An active barrier requires intervention by a human or a monitoring or control system – for example, a gas-detection system or monitor or fire extinguisher.

Taken together, risk assessment and barriers and the human behaviours they encourage produce a system of working frequently called a “gas safety culture”.

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**SGMF**

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A variety of risk assessment methods are available to examine the impact of various scenarios on safety and are generally also applicable to environmental events. SGMF’s “Bunkering guidelines (FP07-1)” provides guidance on these.

The success of risk identification and assessment is primarily about having the right individuals present at the risk assessment, who between them have appropriate experience of the operations associated with the use of LNG.

It is also essential that the methodologies and the results of risk assessment processes are recorded and that any actions on individuals and/or organisations can be formally closed out.

Maintenance is a high-risk activity. Maintenance workers tend to have more serious and more frequent accidents than most other worker groups. The primary causes of this are:

- working alongside equipment that is operating in an unusual way, including frequent starting and stopping
- maintenance often involves unusual work, non-routine tasks in abnormal operating conditions, requiring the use of atypical or unfamiliar, equipment, which often increases the probability of human error (especially if associated with time pressures)
- normal risk control measures and safety protective equipment may be inoperative and may be the subject of maintenance work
- hazards in the workplace and the workplace itself are constantly changing as equipment re-enters service after maintenance or is shut down for maintenance
- risks tend to be greater when working in confined spaces.

The threats and consequences to be considered for maintenance (for a gas-fuelled vessel in addition to those for a conventionally fuelled ship) concern the presence of LNG and/or gas on-board the vessel.

Examples of additional risks surrounding gas-fuelled vessels are shown in Table 3.1
Table 3.1: Additional risks of gas-fuelled vessel maintenance

<table>
<thead>
<tr>
<th>All ships</th>
<th>Additional risks of gas-fuelled ships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encountering hazardous substances</td>
<td>Mobility of gaseous leaks</td>
</tr>
<tr>
<td></td>
<td>Asphyxiant properties of methane and nitrogen (purge gas)</td>
</tr>
<tr>
<td>Potential for uncontrolled ignition of fuels resulting in fires</td>
<td>Flammable atmospheres, where ignition is possible, likely to extend to longer distances</td>
</tr>
<tr>
<td></td>
<td>Greater likelihood for an explosion in a confined space</td>
</tr>
<tr>
<td>Poor housekeeping</td>
<td>Moisture control crucial to avoid ice formation</td>
</tr>
<tr>
<td></td>
<td>Specialist materials required in many systems</td>
</tr>
<tr>
<td></td>
<td>Use of safe electrical systems significantly more extensive</td>
</tr>
<tr>
<td>Insecure structures</td>
<td></td>
</tr>
<tr>
<td>Difficult access or having to work at height</td>
<td></td>
</tr>
<tr>
<td>Finding that engineering and/or safety controls are not working</td>
<td>Increased need for ventilation and gas detection</td>
</tr>
<tr>
<td>Insufficient lighting and surface water in unexpected places</td>
<td></td>
</tr>
<tr>
<td>Noise and vibration</td>
<td></td>
</tr>
<tr>
<td>Excessive heat and cold</td>
<td>LNG-containing systems may remain very cold during maintenance</td>
</tr>
<tr>
<td></td>
<td>Potential for cold burns and hypothermia</td>
</tr>
<tr>
<td></td>
<td>Potential for brittle failure of carbon-steel structures</td>
</tr>
<tr>
<td>High physical workload</td>
<td></td>
</tr>
<tr>
<td>Fumes and dust</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat ingress into LNG causes boiling of the liquid and creation of gas which results in self-pressurisation of LNG-containing systems</td>
</tr>
</tbody>
</table>
An escape of the LNG/gas (the top event/s) from containment systems have potential consequences – primarily to workers but also to the environment and the physical assets involved and, in extreme cases, the public outside the facility. Some of the causes (threats) and consequences (impacts) of gas and LNG leaks are shown in a bow-tie form (other methods may be equally appropriate) in Figure 3.1.

Figure 3.1: Causes and impacts of LNG/gas leaks

Gas-fuelled vessels are designed to contain these threats and minimise any consequences through the placement of various barriers. There are primarily three types of barrier:

- personnel – for example, ensuring competency by appropriate training
- procedures and processes – for example, a safety management system such as a mechanical handling procedure and checklist (barrier) to prevent an item of cargo being dropped on a gas-live system (threat)
- engineering/equipment/technology – for example, a pressure-relief valve (barrier) that lifts when a certain pressure is reached, preventing any further increase (threat)
Barriers also exist for consequences. For example:

- a drip tray (barrier) stops LNG hitting a steel deck structure, thus preventing it from undergoing brittle fracture (consequence)
- the training of personnel (barrier) to stop an LNG leak (consequence) as quickly as possible

Reducing risk is about putting the right barriers – physical and procedural – in the right places at the right times.

Maintenance may fully or partially remove or override one or more of these barriers, with potential reductions in risk mitigation and therefore the increased likelihood of an accident occurring and/or an increase in the consequences of an accident – for example, more workers being affected.

Both the vessel’s and the shipyard’s risk management processes need to accommodate and account for the removal of one or more barriers, as they occur. Additional risk assessment processes may be needed quickly for the modified circumstances if work is to continue uninterrupted. This type of assessment is often called an Operational Risk Assessment (ORA); it should be performed by individuals with the appropriate skills. These individuals might include:

- an experienced facilitator
- senior managers from both sides (for example, master and shipyard project director/manager)
- technical experts from the vessel, shipyard and potentially third parties and/or vendors
- HSE/environmental specialists
- work supervisors and auditors

The agreed risk management processes should define the roles and responsibilities of individuals during an ORA.

Either the vessel’s or the shipyard’s senior management teams may override the advice of the ORA team and stop work if they decide that the risks have not been sufficiently mitigated, pending a detailed review of the risks.
At a minimum, an ORA should be performed every time:

- an active control system and/or ESD/trip system is compromised or becomes unavailable
- an active gas- or fire-detection alarm is compromised or becomes unavailable
- a firefighting system becomes unavailable
- an evacuation route is modified
- a ventilation system in a hazardous area is compromised or becomes unavailable

Any risk assessment, including both normal and dynamic assessments, should be performed to demonstrate that risks to people and the environment have been eliminated where possible, and if not, mitigated to levels as low as reasonably practical (ALARP). The risk tolerability levels produced by an ORA for maintenance should not be worse than normal operating levels, despite some safety systems working at reduced functionality. Risk assessments can also provide insight and information to help define the required safe working practices.

To support ALARP, planning for maintenance should therefore ensure:

- a clear understanding of the builders’ and OEMs’ design intent of the system
- a clear planning of the various maintenance activities to identify any potential interference between activities (SIMOPs)
- a risk assessment is conducted (under no time pressure) on keeping gas/LNG onboard during maintenance work
- review and adjustment of existing risk assessments for new situations – for example, being in the shipyard environment
- safe working systems are in place, with staff properly trained and equipped in their use, and that these systems are followed through execution using procedures such as permit-to-work
• a check on the condition of the vessel as it arrives to show that it is in a state where the risk assessment and safe working systems can be effective
• supervision of practices, risks and work quality provided by owner and Maintainer can significantly improve the safety of the maintenance task required.

More information on risk assessment is presented in Appendix B.

3.3. Hazardous Zones

When gas and/or LNG fuel remain on-board the vessel during maintenance, additional precautions should be taken to ensure the continuing safety of the maintenance process. The extent of the precautions will be determined by risk assessment and should be documented through the permit-to-work system and, most importantly, communicated to the workers and supervisors directly involved in the work.

The sizes of hazardous areas are based on the following broad assumptions:

• inventory, composition and pressure within a system
• the likelihood of leakage based on how frequently the flammable material is present and the number of potential leak sources

The IGF Code uses these assumptions in determining, proscriptively, the location and size of hazardous zones on a ship where a flammable gas may be present. Hazardous zones should be clearly indicated on a ship’s documents, lay-out plans and so on (the hazardous area plan).

Maintenance may change the assumptions, operating pressures and temperatures of equipment and the hazardous material it contains, which may mean that the prescriptive approach in the IGF Code loses its relevance – so a more fundamental understanding of the principles of hazardous area classification may be required.
A “hazardous zone” is defined as:

The three-dimensional space in which a combustible or explosive atmosphere can be expected to be present frequently enough to require special precautions for the control of potential ignition sources

Hazardous zones are categorised as follows:

**Table 3.2: Hazardous area classification**

<table>
<thead>
<tr>
<th>Event</th>
<th>European &amp; IGF Code</th>
<th>US (NFPA 70)</th>
<th>Time guidance (not officially adopted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>An area in which an explosive gas atmosphere is present continuously or for long periods</td>
<td>Zone 0</td>
<td>Class 1 Division 1</td>
<td>Explosive atmosphere for more than 1,000 hours per year</td>
</tr>
<tr>
<td>An area in which an explosive gas atmosphere is likely to occur in normal operation</td>
<td>Zone 1</td>
<td>Class 1 Division 1</td>
<td>Explosive atmosphere for more than 10, but less than 1,000 hours, per year</td>
</tr>
<tr>
<td>An area in which an explosive gas atmosphere is not likely to occur in normal operation and, if it occurs, will only exist for a short time</td>
<td>Zone 2</td>
<td>Class 1 Division 2</td>
<td>Explosive atmosphere for less than 10 hours per year, but still sufficiently likely to require controls over ignition sources</td>
</tr>
<tr>
<td>An area in which an explosive gas atmosphere will not occur in normal operation</td>
<td>Non-hazardous or safe area</td>
<td></td>
<td>No explosive atmosphere present</td>
</tr>
</tbody>
</table>

All zones are equally dangerous if gas is present; the difference is that the probability (likelihood) of gas being present changes and therefore the risk is different.

A hazardous zone is always potentially present whenever there is a low-flash point fuel or its vapour present. The pressure of the gas/vapour is important in determining the size of the hazardous zones.

Table 3.3 shows shipboard systems that may contain gas/LNG if the ship has not been gas-freed for maintenance.
### Table 3.3: Gas/LNG-containing systems

<table>
<thead>
<tr>
<th>System</th>
<th>Hazard</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-deck LNG fuel storage tank and piping</td>
<td>LNG (&lt;10 bar pressure)</td>
<td>Any area which has ventilation intakes immediately around, including below the tank, has the potential to allow gas to enter the ventilation system.</td>
</tr>
<tr>
<td>Below-deck-mounted LNG tanks and pipework</td>
<td>LNG (&lt;10 bar pressure) Gas (&lt;10 bar pressure)</td>
<td>Spaces through which the pipe runs and spaces adjacent to the piping that might be compromised by the work – for example, cutting or drilling through the intervening bulkhead.</td>
</tr>
<tr>
<td>LNG tank connection space</td>
<td>LNG (&lt;10 bar pressure) Gas (&lt;10 bar pressure)</td>
<td>Depends on engine technology selected</td>
</tr>
<tr>
<td>Fuel gas preparation room (or space)</td>
<td>LNG (&lt;300 bar pressure) Gas (up to 300 bar)</td>
<td>Spaces through which the pipe runs and spaces adjacent to the piping that might be compromised by the work – for example, cutting or drilling through the intervening bulkhead.</td>
</tr>
<tr>
<td>Gas fuel piping to engine</td>
<td>Gas (up to 300 bar)</td>
<td>Engine room</td>
</tr>
<tr>
<td>Diesel cycle engines (MEGI)</td>
<td>Gas (up to 300 bar)</td>
<td>Engine room</td>
</tr>
<tr>
<td>Gas turbine engines and generators</td>
<td>Gas (up to 40 bar)</td>
<td>Engine room</td>
</tr>
<tr>
<td>Otto cycle 2-stroke engines</td>
<td>Gas (up to 20 bar)</td>
<td>Engine room</td>
</tr>
<tr>
<td>Otto cycle 4-stroke engines</td>
<td>Gas (up to 7 bar)</td>
<td>Engine room</td>
</tr>
<tr>
<td>Generators, GCUs and boilers</td>
<td>Gas (&lt;10 bar pressure)</td>
<td>Engine room</td>
</tr>
<tr>
<td>Bunkering system</td>
<td>LNG (&lt;10 bar pressure) Gas (&lt;10 bar pressure)</td>
<td>Spaces through which the pipe runs and spaces adjacent to the piping that might be compromised by the work – for example, cutting or drilling through the intervening bulkhead.</td>
</tr>
<tr>
<td>Vent piping system and vent mast</td>
<td>Gas (&lt;10 bar pressure)</td>
<td>Engine room</td>
</tr>
</tbody>
</table>
A more detailed review of hazardous area classification is provided in Appendix C.

Working in Hazardous Areas

Working in hazardous zones is possible but requires additional precautions. As the probability of gas being present is fixed (see below for how to change this), ignition control is the main issue that needs to be addressed with appropriate working practices and precautions.

Ignition control can be achieved in various ways:

- selection of appropriately rated, safe electrical equipment (including mobile/cell phones, handheld radios, battery-operated tools, test meters and lighting)
- selection of appropriately rated, safe mechanical equipment
- non-sparking tools driven by air (no grinding, non-steel materials)
- no naked lights (no welding, smoking and so on)
- ventilation (ensuring flammable atmospheres cannot build up)

Ignition sources are normally assumed to be electrical equipment but can also include typical shipyard activities:

- testing high-power radio and radar
- static electricity generated by sand-blasting and painting systems, air supply hoses and liquid flow in pipes (such as temporary cooling water systems)
- stray earth currents from welding
- naked flames from welding, paint stripping and people smoking
- operation of shipyard cranes
- sparks from grinding and some electrical equipment such as hoists
- workers without anti-static clothing and boots
- lifting and laydown or installation of materials, equipment and scaffolding
- striking metals with sparking tools – for example, metal-faced hammers
• vehicle engines and power generators (particularly gasoline/petrol-fuelled)

**Temporary Declassification of Hazardous Zones**

Hazardous zones are defined for normal operations of the ship. Their size is based on the potential presence of a flammable substance within equipment and piping, and its pressure. Hazardous zones can therefore be temporarily declassified by:

• draining or depressurisation of a system AND
• eliminating the gas/fuel supply to an area through isolation, which must hold and be leak-tight so that no gas can leak into a declassified hazardous zone (see Section 7.1) AND
• after isolation the zone must be successfully purged to remove all flammable gas (see Section 7.2) AND
• confirming the absence of any flammable gas

**Reclassification Note:**

In certain circumstances, the removal of equipment – for example, a gastight door – or isolation of valves to allow maintenance may mean that hazardous areas are enlarged as the limits of the original hazardous area have been changed.

A risk assessment is then required in line with hazardous zone standards (for example, IEC 60079-10-1) to determine the new extent of the hazardous zone.

### 3.4. Safety-Sensitive Areas

This guidance also defines a new concept, a “safety-sensitive area”, where enhanced safety performance is required. Here, working systems and/or procedures can influence either the extent of a neighbouring hazardous area or prevent safety-critical equipment and/or control
systems working correctly elsewhere on a vessel.

Safety-sensitive areas are therefore locations where specialised work procedures may be required or increased control may be necessary to avoid compromising the wider maintenance and/or operational processes.

Examples of safety-sensitive areas include:

- areas adjacent to hazardous areas where worker actions – for example, cutting through or drilling a bulkhead – may encroach on the hazardous area
- areas that contain cables and/or pipes whose operation is critical to the continued operation of the vessel – for example, hydraulic systems initiating ESD
- areas, ducts and piping that are maintained under nitrogen to prevent ignition of any flammable leak
- ventilation fans, ducts and control systems supplying hazardous areas
- fuel lines, both gas and LNG, located on deck beneath where lifting needs to occur
- fuel tanks located on deck beneath where lifting needs to occur
- areas where workers could use pipework, cable trays, and so on, as steps or handholds as a short-cut to using authorised access routes (such as ladders) to work areas

These safety-sensitive areas may be identified using a rigorous review approach – for example, by a HAZID.

An example of an accident during maintenance on an onshore LNG facility is shown in the text box below. Gas leaking from part of the facility found its way into a “safe area” through an unforeseen route: failure in a single barrier. With only a single barrier in place, the work area would have been classified as a safety-sensitive area and the accident might then have been prevented.
Example: Unforeseen migration of gas: Cove Point, US

Unlike fuel oils, gas and vapour are relatively mobile – so they may travel considerable distances and remain flammable. In one instance, at Cove Point in the US, LNG vapour entered an underground electrical cable conduit and spread to an electrical substation building about 70 m away from the leak source. The substation was considered a safe area which gas was unable to enter. Maintenance was going on within the substation building. An electrical arc caused the leaking gas to explode, killing one employee and seriously injuring a second.

Safety-sensitive areas should be: marked up on plans and where possible at the work place using barriers, coloured barrier tape, notices, and so on by the vessel’s owner; be included in QHSE/HSEQ plans; and be reinforced by enhanced monitoring and supervision. The Maintainer should ensure that their staff understand the implications of these areas and follow the correct procedures and behaviours when working in these areas, through briefings and supervision.

Like hazardous areas, safety-sensitive areas will change with time as systems are decommissioned, inspected and maintained, and reinstated. Plans and local marking will need to follow the changes in hazards, as and when they occur.

The safety-sensitive area concept could also be implemented during normal operations for additional procedural safekeeping. Some parts of the cruise industry have started implementing similar techniques.

Example: Access Restrictions During Operations

Cruise ship operators lock some spaces, particularly balconies, that overlook the bunkering station before, during and immediately after LNG transfer operations to prevent untrained personnel (such as passengers) from posing a risk to the bunkering operation and vice versa.
Example: The Importance of Vent System Design
Vent masts may provide common access to many vents from different parts of a vessel. If appropriate isolations are not in place, gas leaking from one part of the vessel may migrate to another area presumed to be gas-free. For example, the vent pipes of the gas circuits from one machinery room (aft) may be connected to the vent pipes of another machinery room (forward).

In one near-miss, the aft machinery room gas engines were restarted after maintenance and an emergency test performed. This required the venting of some gas into the vent system on shut-down. However, in the forward machinery room, the gas pipes were not yet remounted, so gas flowed from the aft machinery room to the forward one via the vent system. Gas detection and a lack of hot work at the time in the forward machinery room meant that nothing happened. The vent pipe design was rectified immediately and a “design warning” issued to ALL customers with the same installation.

Example: Access and Working Restrictions
One vessel operator defines fan rooms for ship ventilation as safety-sensitive zones. Failure may impact the integrity of hazardous zone control techniques. Only authorised staff are allowed to enter and although there is no flammable gas hazard, the level of sensitivity of the equipment requires staff to wear the same PPE and use similar working procedures as for hazardous zones.
4. Differences Between Conventional and LNG/Gas-Fuelled Vessels

The key issue with LNG-fuelled ships is that they contain a liquefied gas which, given heat ingress, can boil and produce sufficient gas to pressurise the tank and pipework that holds it. To reduce the amount of boiling, the fuel system is kept as cold as possible, which requires the use of stainless and high-alloy steels. Should the fuel escape, the gas component is much more mobile and presents more of a safety than an environmental issue.

As in conventionally fuelled ships, the fuel system consists of:

- a bunkering system to fill fuel tanks
- one or more fuel tanks
- a fuel-conditioning system to get the fuel to the correct temperature and pressure
- pipework between the pumps and the fuel-consuming equipment

Each component of a gas-fuelled ship’s fuel system is compared with that of a conventionally fuelled (for example, HFO/MGO) ship in the following paragraphs and in Figure 4.1, which looks at a dual-fuel vessel with both LNG and MGO.
Figure 4.1: Differences in fuel systems

Note: The colour scheme follows ISO 14726, where LNG is represented in purple (ISO is yellow-purple-yellow), gaseous fuel in yellow (ISO is yellow) and oil fuels in brown (HFO brown-black-brown, diesel brown-yellow-brown).
4.1. **Bunkering Facility**

LNG must be contained in pipework and tanks at all times. This means that any pressure applied to move the LNG through the bunker facility will increase the pressure in the fuel tank unless excess gas is returned to the bunker facility. So, unlike conventional bunkering systems, a gas-fuelled ship may have two transfer systems: one to supply fuel and another to return any excess vapour. The pressure and temperature of the fuel (<-130°C and up to 8 bar) means that the rubber hoses used for conventional fuels cannot be used because they would become brittle. Instead, metallic or composite hose systems with single- or double-wall structures are employed.

The differences in the two systems are shown in the Table 4.1 below:

<table>
<thead>
<tr>
<th>Conventionally fuelled ship</th>
<th>Gas-fuelled ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid line only</td>
<td>Gas/vapour and liquid lines required</td>
</tr>
<tr>
<td>Rubber hoses used</td>
<td>Special materials used</td>
</tr>
<tr>
<td>Potential for flammable liquid spills</td>
<td>Self-pressurising so pressure relief is required</td>
</tr>
<tr>
<td>Potential for environmentally damaging liquid spills</td>
<td>Potential for flammable vapour leaks</td>
</tr>
<tr>
<td>Remote actuation/shut-down capability required</td>
<td>Potential for flammable liquid spills</td>
</tr>
<tr>
<td>Overflow tank required</td>
<td>Protection systems provided, or materials selected to protect the vessel’s structure from cryogenic spills</td>
</tr>
<tr>
<td>Fuel cleaning/purification required to remove and dispose of sludge</td>
<td>Remote actuation/shutdown capability required</td>
</tr>
<tr>
<td>Degassing of LSHFO/ULSHFO fuel required</td>
<td>Dry disconnect/connect coupling and break-away couplings required</td>
</tr>
<tr>
<td></td>
<td>Additional firefighting equipment required</td>
</tr>
<tr>
<td></td>
<td>Gas detection required</td>
</tr>
</tbody>
</table>
4.2. Fuel Tanks

LNG fuel systems are made of aluminium, stainless steel or high-alloy steels to make them capable of withstanding the cryogenic storage temperatures required (-163°C to -130°C for LNG). The tanks may be pressurised (Type C) or unpressurised (Types A, B and membrane). Whichever type is selected, the boiling of the fuel in the tank will pressurise it if insufficient fuel is consumed or BOG management equipment is unable to cope with the quantity of BOG generated. Each tank must have a pressure-protection system able to relieve excess pressure to a safe distance through a vent mast. Over-pressurisation of the tank could lead to failure and a loss of LNG into the space containing the tank or onto the main deck. Spilling LNG onto the structure of a vessel would lead rapidly to loss of strength and cracking of the carbon-steel components. To help avoid this, LNG fuel tanks have more instrumentation (temperature, pressure, level and gas detection) than conventional fuel tanks and must be sited away from areas where collisions or grounding may cause damage.

The differences in the two systems are shown in the Table 4.2 on the next page:
### Table 4.2: Fuel tanks

<table>
<thead>
<tr>
<th>Conventionally fuelled ship</th>
<th>Gas-fuelled ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed in the hull</td>
<td>Installed in the hull or on deck; if in the hull must be separated from the machinery space with a cofferdam with A-60 quality insulation</td>
</tr>
<tr>
<td>Maintained warm (heated if LSHFO or ULSHFO is used)</td>
<td>Maintained very cold</td>
</tr>
<tr>
<td>Normal shipbuilding carbon steels used</td>
<td>Insulation required</td>
</tr>
<tr>
<td>Potential for flammable liquid spills (lower risk because of higher flashpoints)</td>
<td>Special materials used</td>
</tr>
<tr>
<td>Potential for environmentally damaging liquid spills</td>
<td>Need to handle expansion and contraction of pipework as temperatures change</td>
</tr>
<tr>
<td>Redundancy or segregation may be required</td>
<td>Potentially hazardous vapour phase</td>
</tr>
<tr>
<td></td>
<td>Self-pressurising</td>
</tr>
<tr>
<td></td>
<td>Pressure-relief system and vent mast required</td>
</tr>
<tr>
<td></td>
<td>Size and location limitations</td>
</tr>
<tr>
<td></td>
<td>Potential for flammable vapour leaks (higher risk because of low flashpoint)</td>
</tr>
<tr>
<td></td>
<td>Potential for flammable liquid spills (higher risk of ignition because of low flashpoint)</td>
</tr>
<tr>
<td></td>
<td>Redundancy or segregation may be required</td>
</tr>
<tr>
<td></td>
<td>ESD system linked to tank</td>
</tr>
</tbody>
</table>

### 4.3. Fuel Preparation Room/Tank Connection Space

Both fuel systems need facilities to take the fuel from the tanks and prepare it for use in the engines, generators or other fuel consumers. Both fuels use pumps; however, to operate an LNG pump the whole pump must be kept cold. For maintenance, the pump must be warmed up prior to removal for inspection and/or repair and will have to be cooled down after reinstatement. In some combinations of LNG storage tank and engine type the gas generated in the fuel tank may be separately removed from the tank and compressed to delivery pressure.

LNG is a much cleaner than most other fuels and so does not require the purification/clarifier systems found on conventionally fuelled vessels.
However, the engine gas fuel injection/admission systems are far more sensitive to particulate content than equivalent oil systems so filtration is usually enhanced in the “fuel gas to engine” pipe systems.

The different safety versus environmental hazards of the fuels mean that potential gas leaks from LNG need to be monitored for and special systems – such as high-volume ventilation or atmospheric inerting using nitrogen – are used to ensure the continued safe operation of the fuel processing equipment.

Although fuel oils need to be heated before use, LNG needs to be vaporised and then heated before combustion. The heating system for LNG is therefore much larger. As the LNG is very cold, water alone cannot be used as the heat transfer medium because if anything went wrong it could freeze. A more complex heating system – often using glycol as an intermediate fluid between the LNG and water or steam – is required. There is no liquid LNG beyond the vaporisers; all subsequent systems handle only vapour/gas.

The differences between the two systems are shown in Table 4.3 on the next page:
### Table 4.3: Fuel preparation room/tank connection space

<table>
<thead>
<tr>
<th>Conventionally fuelled ship</th>
<th>Gas-fuelled ship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Separate room/space for fuel equipment/tank connection is required</td>
</tr>
<tr>
<td>Fuel pumps and filters required</td>
<td>Fuel supply system maintained cold</td>
</tr>
<tr>
<td>Potential for flammable liquid spills (lower risk of ignition because of high flashpoint)</td>
<td>Special materials used</td>
</tr>
<tr>
<td>Potential for environmentally damaging liquid spills</td>
<td>If used, more complex pumps that must be cold prior to start-up</td>
</tr>
<tr>
<td>Warming of LSHFO/ULSHFO required to allow effective atomisation</td>
<td>Fuel line strainers (filters)</td>
</tr>
<tr>
<td>Air atomisation required for MGO</td>
<td>High-pressure (up to 300 bar) gas may be present</td>
</tr>
<tr>
<td></td>
<td>Additional equipment present – for example, vaporisers, BOG/gas compressors, intermediate heating media</td>
</tr>
<tr>
<td></td>
<td>Potential for flammable vapour leaks (higher risk because of low flashpoint)</td>
</tr>
<tr>
<td></td>
<td>Potential for flammable liquid spills (higher risk of ignition because of low flashpoint)</td>
</tr>
<tr>
<td></td>
<td>Redundancy or segregation may be required</td>
</tr>
<tr>
<td></td>
<td>Flammable gas detection required linked to ESD system</td>
</tr>
<tr>
<td></td>
<td>Dedicated ventilation required</td>
</tr>
<tr>
<td></td>
<td>Nitrogen (asphyxiant) supply required</td>
</tr>
</tbody>
</table>

### 4.4. Fuel Isolation (Gas Valve Unit)

Isolation of gases and liquids depends primarily on their pressure; the higher the pressure the greater the level of isolation needed. At low pressures – for example, in a fuel oil/MGO system – a single isolation valve is required. At higher pressures (typically >50 bar) two isolation valves are required to ensure that if one leaks, isolation remains effective. This is often backed up with a depressurised section between the two valves to ensure that there is no pressure build-up. This section needs to be connected to the vent system via a valve which is opened to provide protection. This is called a double-block and bleed system. In many scenarios all three valves are combined into one piece of equipment. The IGF Code requires a higher level of isolation reliability in some
applications to that suggested under international good practice. In most instances, this results in the use of double-block and bleed system for isolation, but other isolation strategies of equal reliability are also available (see Section 7.1). In these applications the use of single- or double-block valves is not accepted.

The differences are shown in the Table 4.4 below:

<table>
<thead>
<tr>
<th>Conventionally fuelled ship</th>
<th>Gas-fuelled ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-valve isolation</td>
<td>Double-block and bleed isolation for each fuel consumer, with the bleed connected to the vent system</td>
</tr>
</tbody>
</table>

### 4.5. Fuel Piping

The potential safety hazards of LNG mean that leaks from LNG and natural gas piping need to be monitored for and controlled using special systems – such as high-volume ventilation or a pipe-in-pipe system/ double walled pipe where the outer pipe can be monitored for leakage from the inner pipe or an inert gas such as nitrogen used. The IGF Code requires that piping should be sited away from areas where it could potentially be damaged.

The differences in the two systems are shown in the Table 4.5 below:

<table>
<thead>
<tr>
<th>Conventionally fuelled ship</th>
<th>Gas-fuelled ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional single-skin, carbon-steel piping</td>
<td>Potential for flammable vapour leaks (higher risk as a result of its low flashpoint)</td>
</tr>
<tr>
<td>Potential for flammable liquid spills</td>
<td>Limitations on pipe routing locations</td>
</tr>
<tr>
<td>Potential for environmentally damaging liquid spills</td>
<td>Pipe-in-pipe system with nitrogen or ventilation in the outer pipe to stop ignition of any leaks from the fuel gas in the inner pipe</td>
</tr>
<tr>
<td>Heat-traced fuel piping</td>
<td>Redundancy or segregation may be required</td>
</tr>
</tbody>
</table>
4.6. Machinery Spaces

Gas must enter the machinery spaces to allow its use as a fuel so mitigation measures need to be increased beyond those described previously. There are two additional protection options: firstly, a sealed system where gas cannot escape after a single failure (“gas safe”); and, secondly, a system which ensures that, if a leak is detected, all equipment is made safe, by shutting it down should it be able to ignite the gas leak (“ESD protected”). Conventional fuels do not produce very much flammable vapour and so do not require these types of protective system.

The differences in the two systems are shown in the Table 4.6 below:

Table 4.6: Machinery spaces

<table>
<thead>
<tr>
<th>Conventionally fuelled ship</th>
<th>Gas-fuelled ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential for flammable liquid spills</td>
<td>ESD-protected or gas safe machinery spaces required</td>
</tr>
<tr>
<td>Potential for environmentally damaging liquid spills</td>
<td>Potential for flammable liquid spills</td>
</tr>
<tr>
<td></td>
<td>Additional ventilation requirements</td>
</tr>
<tr>
<td></td>
<td>Flammable gas detection required</td>
</tr>
<tr>
<td></td>
<td>Potential for flammable vapour leaks</td>
</tr>
</tbody>
</table>

4.7. Vent System for Hazardous Material

LNG will vaporise into gas as it absorbs heat from its surroundings. If LNG is trapped, the formation of gas will start to pressurise the equipment or piping. Without a pressure-relieving system, the pressure build-up will ultimately damage the system.

The vent system receives any gas released by the relief systems and directs it to a safe location, typically a vent mast. The vent mast is a pipe or a group of pipes that terminates high above the deck and is positioned within the vessel’s designated gas hazardous zone. Through design and operational procedures, it minimises the impact on the vessel or its crew.
while the vessel is in normal operation. The ability of the relief system to operate as designed by releasing excess gas to the atmosphere must be duly considered in line with the planning and maintenance topics covered in further detail in this document.

Conventional fuels can be drained back into a tank, leaving very little vapour behind. Where possible, LNG and BOG are also returned to the fuel tank.

The differences in the two systems are shown in the Table 4.7 below:

<table>
<thead>
<tr>
<th>Conventionally fuelled ship</th>
<th>Gas-fuelled ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vent locally to atmosphere when required</td>
<td>Pressure- and thermal-relief valves and associated piping</td>
</tr>
<tr>
<td></td>
<td>Vent mast</td>
</tr>
</tbody>
</table>

### 4.8. Ventilation Systems

The relative mobility of gases compared with liquid spills means that ventilation is key in controlling their flammability. There are two types of system: firstly, air locks (double doors) to stop potentially contaminated air getting into safe spaces, and, secondly, fan-assisted, high-volume ventilation systems to ensure that flammable gas concentrations never reach the lower flammable limit (LFL).

Conventionally fuelled ships have lower ventilation requirements (mostly for human comfort) and do not typically have air locks and over-pressurised accommodation (tankers and hazardous cargoes excepted).

The differences in the two systems are shown in the Table 4.8 on the next page:
### Table 4.8: Ventilation systems

<table>
<thead>
<tr>
<th>Conventionally fuelled ship</th>
<th>Gas-fuelled ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated ventilation systems for potential fuel leaks not required</td>
<td>Dedicated ventilation systems for potential fuel leaks</td>
</tr>
<tr>
<td></td>
<td>Air locks and over-pressurised accommodation</td>
</tr>
<tr>
<td></td>
<td>High-volume, fan-driven ventilation systems with inlet dampers</td>
</tr>
</tbody>
</table>
5. Managing Maintenance in General

Owners take very different approaches to maintenance and repair. However, maintenance – whether running repairs during a voyage or in a shipyard during a dry dock – needs to be managed effectively to ensure safety and environmental responsibility.

Maintenance management should at all times prioritise in the following order:

1. protection of people (ship’s crew, shipyard personnel, subcontractors, OEMs and any other third parties)
2. protection of the environment (such as avoiding the venting of gas and environmentally damaging liquid spills)
3. protection of assets and property (the vessel itself, the shipyard and third-party equipment)
4. protection of business continuity (work progress, profit, reputation and so on)

Figure 5.1 shows an overview of a maintenance process (in orange). It shows the importance of risk assessment and mitigation through the development of specific working practices and operational/maintenance plans. It also introduces risk management methods, primarily a permit-to-work scheme, to ensure safety throughout the whole maintenance process. Through colour coding, Figure 5.1 shows roles and responsibilities with the owner shown in blue, the Maintainer (possibly a separate part of the vessel owner) in green, and joint actions in yellow.
Figure 5.1: Maintenance process overview

- **Joint work specification/scope**
- **Risk identification & assessment**
  - Owner LNG expert
  - Maintainer LNG expert
  - Risk mitigation
- **LNG/gas and pressure - management procedures**
- **Job safety analysis**
- **Working procedures / method statements**
- **Equipment**
- **Training**
- **Work area preparation**
- **Joint authorisation**
- **Briefing**
- **Work performance**
- **Permit-to-Work System**
- **Owner supervision**
- **Maintainer supervision**
- **Continuous, dynamic risk identification & assessment by all**
This chapter will consider each of the processes in Figure 5.1, under the following headings:

- roles and responsibilities
- risk identification and assessment
- risk mitigation – shipowner’s preparations for maintenance
- risk mitigation – maintainer’s preparations for maintenance
- risk management

In addition, the impacts on emergency and contingency planning are reviewed should all the risk identification, assessment and management systems fail. Finally, the requirements for reporting and auditing are examined.

### 5.1. Roles and Responsibilities

Safety onboard ships is covered by the ISM Code while in shipyards (onshore) country specific legislation is used – for example, the Seveso III Directive in Europe or the Health and Safety at Work Acts in the UK. A safety and environmental policy from both parties that covers maintenance would be expected. An example of a policy is shown in Figure 5.2.
The shipowner is always responsible for the gas/fuel onboard the vessel and must therefore define: what precautions/mitigations are required, how they are to be implemented, and how they should be communicated to other parties (such as OEMs, the shipyard and the relevant authorities).
In the context of ships arriving at shipyards, this is discussed further in Section 6.6 and may require specific local licences and regulations to be in place, as described in Section 6.1.

All parties are responsible for risk assessment, risk management and safety. Each party has a duty of care to their staff, and by implication to people from other companies and bodies who are working at the same location either, on the vessel onshore, or on neighbouring vessels and facilities.

This responsibility of the shipowner does not take away any responsibility from the managers of the maintenance staff and the workforce themselves in managing their safety and that of those around them. The role of the owner, as the technical expert, is to confirm the quality and competence of the work and to stop hazards developing and escalating by monitoring its progress.

Supervision of work progress (by the Maintainer) should be independent of those requiring the work to be done and approving the result (the owner). This demarcation is clear in a ship-to-shipyard approach but must be maintained when a vessel’s crew is both requiring and doing the work. In this case, the seniorities of the work supervisor and the work owner should be similar.

The responsibilities of each party are summarised in Table 5.1.

The vessel’s charterer normally has no responsibilities during dry-docking as this is an off-hire event and all work is at the responsibility and cost of the vessel’s owner. The charterer only has responsibility if the work has been specified and undertaken at its request (with the owner’s agreement) – for example, to convert a vessel to run on LNG as a fuel.

Flag states have a duty to check that the construction (including modification and repair), equipment and seaworthiness of ships (through maintenance) should conform to generally accepted international regulations, procedures and practices and to take any steps which may be necessary to make sure owners and maintainers observe them.

In practice, the Classification Societies can perform statutory duties concerning ship safety on behalf of Flag states, in addition to statutory inspections under classification rules.
### Table 5.1 Roles and responsibilities during maintenance

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Vessel owner</th>
<th>Vessel Maintainer</th>
</tr>
</thead>
</table>
| **Hazardous materials, including LNG/gas fuel** | • The owner is responsible for the safety of hazardous materials stored or used on the vessel, most notably the gas/LNG.  
• The owner is also responsible for any activities which involve removal or introduction of gas/fuel to make areas safe or to re-commission them after maintenance. | • The Maintainer is responsible for hazardous materials used for maintenance – for example, welding gases stored externally in a ship yard. |

| Risk identification and assessment | Jointly responsible | Jointly responsible |

| Management of safety | Jointly responsible for the safety of:  
• the vessel’s crew and any owner employees/representative present;  
• any owner employed or controlled subcontractors/specialists/OEMs; and  
• everyone on board at all times, whether crew, owner employees, subcontractors, OEMs and so on. | Jointly responsible for the safety of:  
• any shipyard workers or controlled subcontractors/specialists. |
<table>
<thead>
<tr>
<th>Maintenance management</th>
<th>Vessel owner</th>
<th>Vessel Maintainer</th>
</tr>
</thead>
<tbody>
<tr>
<td>• management of the agreed permit-to-work system for the project handover, for maintenance of equipment items and/or complete vessel systems and/or vessel areas.</td>
<td></td>
<td>• managing the agreed permit-to-work system for the maintenance.</td>
</tr>
<tr>
<td>• management and control of specific vessel areas.</td>
<td></td>
<td>• following agreed working practices, controls and supervisory instructions.</td>
</tr>
<tr>
<td>• provision of documentation – for example, OEM manuals, drawings, risk assessments and so on – required to allow maintenance to happen.</td>
<td></td>
<td>• respecting safety signage and risk assessments.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ensuring workers understand, and are suitably trained and equipped to meet the job requirements imposed by the permit-to-work system.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• defining the levels of supporting resources that are required – for example, the need for fire guards and/or rescue personnel.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ensuring documentation is provided on completion of the maintenance work to allow the equipment/system/area to be re-commissioned.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supervision</th>
<th>Vessel owner</th>
<th>Vessel Maintainer</th>
</tr>
</thead>
<tbody>
<tr>
<td>• supervising the safety and quality of the work, whether done by the crew, the shipyard or subcontractors.</td>
<td></td>
<td>• defining how supervisors and workers are briefed to do maintenance, particularly if this involves hazardous and/or safety-sensitive areas (for example, tool box talks).</td>
</tr>
</tbody>
</table>
5.2. Risk Identification and Assessment

Once the maintenance scope has been agreed, risk identification and assessment should commence. The prime aim of this guidance is to consider maintenance and repair, however vessel modification may also take place using these processes. If modifications are to be made, a more robust “management of change process” will also be required (see Appendix D).

This section covers the following scope:

5.2.1. Risk Identification

The principal hazard onboard a gas/LNG-fuelled vessel will be the fuel, in both liquid and gaseous forms. Maintenance is similar to that on conventionally fuelled vessels, except for the following:

- risk assessment requires consideration of additional hazards and mitigations as the result of the (potentially) gaseous nature of the fuel:
  - the fuel is a liquefied gas which will vaporise and, if volume change is constrained, lead to a significant increase in local
pressures – everybody involved should understand BOG management practices

- gas/LNG needs different detection methods, actions (alarms) and behaviours (escape) than conventional fuels
- working methods need to change because of the different hazards, so work permits will be more stringent and require more risk assessment
- isolations may need to be positively proven as the implications of a release are greater
- emergency scenarios are different because fire is no longer the controlling event – gas/LNG forms gas clouds with potential for delayed ignition, jet fires and the potential for explosions (these issues also need to be covered by the LNG-ready criteria)
- firefighting and medical emergencies are different

- Because of the cryogenic nature of the fuel:
  - difficulty in totally removing water means that pneumatic testing, which involves considerably higher energy and therefore more onerous safety precautions, is often preferred to hydro-testing (see Section 7.9)
  - the time involved in warming up before repair, and cooling down after it, requires greater attention to cleanliness to avoid blockage and subsequent rework (see Section 7.5)
  - more exotic materials (gaskets, seals, greases and so on) are used, requiring different storage and handling behaviours (see Section 7.10)

- personnel must be trained to be competent to operate, maintain and/or repair a low flashpoint-fuelled vessel:
  - safety systems are likely to be more extensive and critical, resulting in the need for more competency in staff (for example, the LNG specialist role) and, in addition, interactions with other systems may lead to problems (for example, power may need to be maintained at all times)

- maintenance and repair of (Ex) electrical equipment certified for hazardous areas needs particular attention as it is significantly larger in scope and more diverse in location
5.2.2. Risk Assessment
Risk assessment is discussed in Section 3.2 and Appendix B.

5.3. Risk Mitigation – Shipowner’s Preparations for Maintenance

This section looks at how owners should plan and prepare for maintenance. It covers differences from conventionally fuelled ships and the need for a gas-management plan to monitor and control the pressure of any LNG in the vessel’s fuel tanks during maintenance activities. The scope of this section is shown below:

Maintenance processes for gas-fuelled vessels will be similar to those for conventionally fuelled vessels (the shipyard perspective is given in Section 6.4). The owner’s specialist LNG/gas engineer should lead the identification and development of any new maintenance procedures required for vessel components that use gas/LNG.

The main difference in planning how to maintain a gas/LNG-fuelled vessel compared with a conventionally fuelled vessel are the additional time and costs of:

- the supply of specialist equipment, materials and spare parts
- the need for specialised working procedures
- suitably skilled personnel to work on the vessel
However, the most important difference during maintenance is the mobility of any gas, should it leak or be released from a containment system. This requires additional checks and changes in working practices and control processes to minimise risks. A work control process is a means of proscribing how work must be done – for example, through a permit-to-work scheme and working procedures – communicating this to the workforce and then, through appropriate supervision, ensuring that the actions are completed correctly and effectively.

A key driver will be the condition of the vessel when it enters the shipyard (see Section 2). The three possible scenarios are:

- all of the vessel’s systems contain LNG or natural gas (gassed-up and cold)
- part of the vessel’s systems contain LNG or remain under natural gas
- none of the vessel’s systems contain LNG fuel or natural gas

This section looks at safe working systems and supervision in more detail because people may become complacent and look for ways around complicated systems to make their lives easier. Often, they may not be aware of the potential adverse implications of such actions. One of the aims of training is to highlight the importance of doing a task in the correct way – which means following the specified working procedures and implementing the necessary precautions.

5.3.1. Gas Pressure-Management Plan

Because LNG (or LPG or ethane) is a boiling liquid, heat ingress will cause some of the liquid to vaporise. One volume of LNG vaporises to about 600 volumes of gas at atmospheric pressure and ambient temperature. In a constant volume – for example, in a tank whose inlet and outlet valves are closed or where LNG is trapped in pipework between two closed valves – this will lead to a rise in pressure.

Unless the LNG tank pressure is managed, relief valves designed to protect the integrity of the fuel tank will open at a pre-defined pressure, allowing excess gas to enter the vent system to be discharged to the
atmosphere via the vent mast. Thermal-relief valves perform the same function for isolated pipe sections.

Failure to maintain adequate pressure control will lead to venting and the potential escalation to a fire or explosion should the gas plume ignite, or environmental damage if it does not.

Vent Mast
The vent mast and the pressure-relief valves (PRVs) that separate the mast from the LNG fuel tank protect the integrity of the tank. So they should not be disabled (unless sufficient redundancy exists) to prevent gas discharge because overpressure in the tank could lead to its rupture and spillage of cryogenic liquid onto the vessel and into the surrounding environment.

A vent mast may consist of a single pipe where all gas-relieving equipment/valves are mixed or multiple pipes routed together. The IGF Code gives specific information on the sizing of these valves and pipes.

Thermal-Relief Valves
Similarly, where a liquefied gas such as LNG might become trapped and start to pressurise, the pipe system should be protected by a thermal-relief valve (TRV) which allows pressure to escape via dedicated pipework into the vent mast or into the tank.

The rate of pressure rise within an LNG tank depends on the amount of heat entering the tank, which in turn depends on the thickness and type of insulation used, and the volume and quality of the LNG in the tank. The very large temperature difference between the LNG and ambient conditions means that the temperature at a particular shipyard resulting from its geographical location makes little difference.

Every ship will have a heat ingress rate provided by its tank manufacturer as part of the documentation for the ship received at the end of construction. For example, one shipowner identified the heat ingress into its foam-insulated Type C tank as 0.023 W/m²/°C.
Heat ingress depends on many factors, including:

- the size of the tank, specifically the surface area for heat transfer compared with the tank volume
- the type and thickness of insulation used on the tank

Heat ingress can also be described as the amount of BOG generated during a day as a percentage of the tank’s contents. BOG generation or holding time curves are provided by tank manufacturers and approved by Class Societies. Pure methane is generally used for calculations rather than actual LNG composition to produce conservative estimates of gas production. These curves can be used to predict LNG tank gas pressure build-up.

Manufacturers’ original holding time curves may include the minimum hotel load (as included in the IGF Code). This load may be absent because of maintenance activities. These holding time curves should be reviewed (for example by closing LNG tank valves while filled at various levels to examine pressurisation rates).

Tank insulation can degrade over time so the tank manufacturer’s calculations will become progressively less accurate. Accuracy will also be affected by sea conditions prior to yard entry, and fuel quality. Ships should be able to recalibrate their BOG generation/holding time curves using actual data. For vessels with multiple tanks, one tank can be isolated for a period and the rate of temperature and pressure increase recorded to determine new curves. If there is only one tank, it may still be possible to isolate it if the vessel is capable of dual-fuel operation and only oil is used during the recalibration process. Any recalibrated curve should be compared with the original tank manufacturer’s curve and significant discrepancies examined further.

However, in most instances it is the trend – the rate of change – that matters rather than absolute accuracy.

A tank condition report should be produced on arrival and every subsequent 24 hours. The report should cover the temperature, pressure and level in the tank and be used to predict BOG rates to predict trends. These reports should be shared with the yard and may be required by the regulator.
Figure 5.3 shows the actual change of pressure for a Type C LNG tank on a dual-fuelled vessel. The rate of pressure change (the blue line) varies considerably with tank level (the orange line). When no LNG or BOG is being removed (the flat part of orange line) the rate of increase in pressure is much higher.

Each vessel will therefore require a pressure-management plan. The primary concern is the LNG fuel tank but plans should also cover other areas of the vessel where liquefied gas can be present and trapped.

LNG tank pressure must be actively controlled and monitored during the maintenance/dry dock phase. The manufacturer of the LNG fuel tank should assist the owner in the tank pressure-management process. When the tank pressure nears an established high value as stated in the pressure-management plan, the ship operator/shipyard will need to work through a tank pressure-management process.

Regulators will require notification when the maximum acceptable pressure (MAP) is reached: 70-85% MAVRS (Maximum Allowable Relief Valve Setting) is suggested as an appropriate threshold for notification.
A layered pressure-management plan approach is recommended:

- A normal plan implemented by the shipowner/operator to avoid venting of the tank contents during the dry-docking; this plan should be incorporated into the shipyard’s emergency plan. The plan should include, as a minimum:
  - the procedures used
  - the human and equipment resources required
  - the communication protocols
- An emergency/contingency plan from the shipyard is needed in case the vessel’s plan fails to perform as intended (see Section 6.2).

Several options are available for tank pressure-management under the shipowner’s control:

- ensuring that the maintenance/dry dock duration is sufficiently short so that the tank does not pressurise sufficiently to lift the pressure-relief valves.
- running gas-consuming equipment – such as boilers, generators and engines – during dry-docking to consume BOG. Active BOG control should be the norm and first line of defence in the gas-management plan.
- bunkering with “cold” LNG to reduce the temperature and pressure in the LNG tank.
- combustion of BOG in a flare, thermal oxidiser or catalytic gas combustion unit (GCU).
- re-liquefaction of the BOG using a refrigeration system.
- sub-cooling of the LNG using a refrigeration system.
- de-bunkering the LNG.
- venting the gas to the atmosphere at a safe location (IGF Code limits venting to emergency situations only)

More details are provided in Table 5.2.
### Table 5.2: Gas pressure-management plan options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensuring that the maintenance/dry dock duration is sufficiently short so that the tank does not pressurise sufficiently to lift the pressure-relief valves.</td>
<td>It may be appropriate to set a tank pressure margin to the pressure-relief valve (PRV) setting when the vessel enters the yard to provide an “emergency action” period. This pressure margin could be based on a pressure a percentage below the PRV pressure (for example, 75% of set pressure) or a time-based limit (36 hours to set pressure).</td>
</tr>
<tr>
<td>Running gas-consuming equipment such as boilers, generators and engines during dry-docking to consume BOG. Active BOG control should be the norm and the first line of defence in the gas management plan.</td>
<td>LNG is removed from the fuel tank in the normal way, either pumped or under pressure, and distributed to gas-consuming equipment on the gas-fuelled ship. Some of these systems or the pipework that supplies them may be out of operation through maintenance.</td>
</tr>
</tbody>
</table>

In a dry-dock environment, a boiler is likely to be the easiest equipment to use. Use of the engines, while giving a significantly higher consumption rate, will require cooling water to be provided by the shipyard. In both cases, all of the auxiliary support systems (including controls and monitoring) will need to be functional throughout the dry-docking.

The owner should therefore have a mitigation plan for additional services and/or equipment to allow continued use of BOG users/fuel consumers – for example, the yard providing sufficient cooling water to run auxiliary engines. Mitigation plans should note that centralised systems such as cooling water may have limitations where a failure on one vessel may lead to a cascade failure (cooling water pump, power supply and so on) that affects other vessels using the same service.
<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunkering with “cold” LNG to reduce the temperature and pressure in the LNG tank.</td>
<td>Delivering a load of LNG which is colder than the contents of the tank will cool the original tank contents by mixing.</td>
<td>Not a long-term solution; it will only temporarily reduce the tank pressure. Because the tank ends up fuller, and the vapour space smaller, gas pressurisation will resume at a higher rate than before.</td>
</tr>
<tr>
<td>Combustion of BOG in a flare, thermal oxidiser or catalytic gas combustion unit (GCU).</td>
<td>Excess gas is combusted in a GCU to produce CO₂ and water, which can be vented close to the ship or at some other suitable location in the yard. The GCU is likely to be mounted on a skid for temporary use, either owned or hired in by the shipyard, but could be integral to the gas-fuelled ship. Gas would be supplied either through a connection to the vent header prior to the vent mast pressure-relief valves or via the bunkering vapour return line.</td>
<td>Flaring is accomplished by combusting the vented natural gas. The resulting emissions have significantly less impact as a greenhouse gas than venting methane directly. Gas-fuelled ship gas vent masts are not designed to flare, so a special thermal oxidiser is required – effectively a boiler without any heating load. Thermal oxidation is a controlled process that decomposes hazardous gases at a high temperature and releases them into the atmosphere. The units are purpose-built and are commonly found on LNG carriers where BOG management plays a key role in managing cargo-tank pressure. The land-based LNG industry uses portable flaring units for various LNG BOG management scenarios. These could be made available via the shipyard, connected to the IGF vessel via the vapour return line in the bunkering system.</td>
</tr>
<tr>
<td>Re-liquefaction of the BOG using a refrigeration system.</td>
<td>Involves refrigeration, normally of the gas within the tank, by taking some of the gas directly, or via a BOG compressor, through a heat exchanger linked to a refrigeration system which re-liquefies the liquid by cooling it. An external reliquefaction unit would be connected via the vessel's bunkering vapour return line.</td>
<td>The re-liquefaction unit is likely to be mounted on a skid for temporary use, either owned or hired in by the shipyard, but could be integral to the gas-fuelled ship.</td>
</tr>
</tbody>
</table>
**Table 5.2: Gas pressure-management plan options (continued)**

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-cooling of the LNG using a refrigeration system.</td>
<td>Involves removal of a flow of LNG for cooling so that it is several degrees below its boiling point at a specific pressure, by flowing it through a refrigeration system and then returning it to the tank.</td>
<td>The refrigeration unit is likely to be mounted on a skid for temporary use, either owned or hired by the ship yard, but could be integral to the gas-fuelled ship.</td>
</tr>
<tr>
<td>De-bunkering the LNG.</td>
<td>Some, or all, of the LNG is removed from the vessel using either a pump, or the pressure in the storage tank, into a road tanker/ISO container or a tank located within the shipyard.</td>
<td>The process is relatively straightforward but effectively only transfers the problem from the vessel to another storage tank which would need to control its own pressure and BOG. This activity will require additional consent (reverse of bunkering) from the competent authorities before it begins.</td>
</tr>
<tr>
<td>Venting the gas to the atmosphere.</td>
<td>BOG (methane) is discharged to the atmosphere via the vessel’s vent system/mast or at another safe location.</td>
<td>The greenhouse gas impact of methane on the atmosphere is about 30 times that of CO₂ (IPCC AR5). Large-scale release of methane as a normal operating procedure is generally not tolerated by competent authorities and should be considered only under abnormal circumstances (as a contingency plan) – for example, to prevent the immediate danger of tank over-pressurisation, and when other options have proven unfeasible.</td>
</tr>
</tbody>
</table>
In all scenarios, the pressure-relief/vent mast system needs to be capable of operation to protect the integrity of the fuel tank including from over-pressurisation. Although venting to the atmosphere is strongly discouraged, the option must be available for use and a cold-gas dispersion study should be conducted to identify the hazardous area in case of venting in a dry dock. If the vent mast or multiple pressure-relief valves need to be maintained, the tank may need to be gas-freed.

When selecting a method, the shipowner should consider:

- robustness of the operation – for example, does the method require:
  - a power supply which may fail (black out)
  - guaranteed operation of another unit or control system
  - the operation of complex machinery that may fail
- safety implications:
  - adding additional fuel inventory
  - movement of machinery (for example, engines)
  - hot surfaces (and, in very specific circumstances, the potential for ignition)
  - the passing of gas/vapour through or into spaces where maintenance is occurring
- environmental impact – for example, CO\textsubscript{2} produced by combustion.
- the ability (configuration, size and pressure drop) of the existing vapour-return pipework or a temporary flexible hose to dispose of the BOG effectively.
- the need for temporary connections and pipework which may not be so robustly designed and/or supported, compared with ship systems, and therefore may be more leak/failure-prone.
5.4. **Risk Mitigation – Maintainer’s Preparations for Maintenance**

5.4.1. **Safe Working Plans**
Development of safe working plans and systems is primarily about risk assessment to determine what might possibly go wrong, and then developing appropriate control and/or mitigation measures. The scope of this section is shown below:

Control measures can be based on:

- personnel – for example, ensuring competency by appropriate training in the maintenance task
- procedures and processes – for example, a permit-to-work management system or a revised welding procedure
- tools and equipment – for example, non-sparking, air-driven tools
Reducing risk is about putting the right barriers or control measures in the right place at the right time. It is important to recognise that gas/LNG-fuelled ships have different requirements – such as more exotic metallurgy, very low temperatures and leak scenarios – compared with conventional ships. Shipowners should meet these requirements through the ISM Code. Similar processes are required onshore (defined by local law) – for example, the United Kingdom’s Health and Safety at Work Acts.

Many techniques, both physical and procedural, can reduce the likelihood of a risk occurring or mitigate the scale of the consequences. These include:

Personnel behaviours:
- trained and competent staff working in a professional way
- the correct use of appropriate tools and safety equipment
- effective communication, supervision and management

Management systems:
- maintenance manuals
- no-smoking areas/protocols
- safe working procedures
- a permit-to-work system

It is often appropriate to employ more than one control measure to achieve safe working.
Example: Removing a Valve Located Within a Hazardous Area

Maintenance procedures can involve using the following practices as barriers to prevent a hazardous event occurring or to mitigate its consequences:

- gas detection and monitoring to identify leaks
- ventilation to keep flammable gas compositions below flammable/explosive levels
- the use of lighting that will not ignite flammable gases in the work area
- the use of non-sparking tools to remove the valve

A job safety analysis (JSA) is one systematic way of positively changing worker behaviour around potentially risky tasks by examining the connections between workers, the tasks, their tools and the work environment. The aim of a JSA, which can consist of a range of techniques, is to help integrate good health and safety principles and practices into an operation. It does this by specifying the task and then breaking it down into a sequence of steps whose risks/hazards can be identified and then mitigated. The target end result of a JSA is a safe working procedure for a particular activity which can be used as part of the risk management process.

Working methods and practices need to be modified for use on LNG/gas-fuelled ships, for the following reasons:

- different construction materials and their interactions with normal ship steels
- the ability of any leaking gas to migrate into different areas and enter areas such as instrumentation, where a spark could cause a fire/explosion
- the cryogenic temperatures involved may extend the timescales for intervention
- cryogenic temperatures may freeze any moisture present, leading to blockages or reduced system/equipment performance
Table 5.3 is a non-exhaustive list of procedures that will be required, above and beyond normal ship operations, or, if existing, are likely to require enhancement.

Working procedures, even when regarded as good practice, may need to be modified to be effective in a particular location for a particular task. The work group and its supervisor should review each procedure in the context of the job and determine whether it needs adjustment; if so, they should consider whether they have the necessary authority to make the changes or whether they should refer changes to more senior levels of management. Once the review is complete, the supervisor should:

- discuss the hazards and controls – for example, with a toolbox talk
- delegate responsibilities
- ensure that all necessary equipment is available, including personal protective equipment
- ensure that contingencies such as firefighting are understood
- agree communication channels

If at any time during the work circumstances change, then work should be stopped and the review process repeated until an acceptable solution is found.
<table>
<thead>
<tr>
<th>Area</th>
<th>Procedure enhancement</th>
</tr>
</thead>
</table>
| Flammability and mobility of gas/vaporised LNG | • personal equipment such as phones, smoking paraphernalia, and other non-intrinsically safe electronics, such as radios and tools, should not be allowed in gas hazardous areas  
• electrically driven tools may need to be replaced with pneumatic or hydraulic equivalents in gas hazardous areas to avoid potential sparking  
• tools made of steel which could cause sparks when dropped or striking other steels may need to be replaced in gas hazardous areas  
• long-sleeved overalls and safety footwear should to be worn, and when working in hazardous and safety-sensitive areas, should be “anti-static”; suitable gloves (correctly worn) and eye protection may be required where there is a risk of contact with LNG  
• increased use of personal gas monitors and portable flammable gas-detection technology, appropriately calibrated, within an area/space |
| Maintaining safe electrical equipment         | • more safe-type instrumentation and electrical systems are anticipated and are dispersed throughout the vessel requiring more attention during maintenance activities                                                    |
| Hot work/welding                              | • stainless steels and aluminium need different welding skills and materials to carbon steel; and welders should be suitably qualified  
• crack-detection (NDT) procedures are also different  
• earthing requirements for welding change to avoid excessive currents running through the ship hull, potentially causing ignition of leaking gas  
• weld splatter from carbon steel welding must not hit stainless steel or aluminium components because this can cause galvanic corrosion                                                                 |
| Storage, handling and working with exotic materials (such as stainless steel and aluminium) | • gaskets and seals in “normal” materials may not be effective at cryogenic temperatures – for example, metals and graphite rather than elastomers  
• cryogenic insulation can give off toxic gases if ignited – for example, by careless welding or grinding activities |

**Table 5.3: Recommended enhanced working procedures**
<table>
<thead>
<tr>
<th>Area</th>
<th>Procedure enhancement</th>
</tr>
</thead>
</table>
| The need for more rigorous cleanliness and housekeeping practices, particularly moisture ingress control | • water/moisture left in pipework systems may freeze during operations  
• ice formation in valves will damage valve seats/sealing components, leading to leakage  
• high levels of atmospheric moisture during installation or damage to external seals/vapour barriers will make cryogenic insulation ineffective  
• an inability to ensure full drying out means that pressure testing with water is not possible and dry air should be used instead, with a significant increase in the energy involved should a component fail  
• dry air for LNG purposes requires a dew point below -70°C (if not available, nitrogen - dew point of -70°C can be used) |
| Extreme cold and contraction and expansion | • on cooling to LNG temperatures (or warming of a cold system to ambient) steelwork will contract (or expand) considerably, with consequences for how piping should be supported if leaks are to be avoided  
• cold surfaces can cause injury if touched without appropriate gloves or full-body clothing  
• driver alignment of cryogenic machinery requires understanding of the direction of thermal movement (note that most machinery clearances are given at 20°C or, in extreme temperatures, the range -40°C to +50°C; correct clearance measurement may be difficult or unclear) |
| Hazardous and confined space entry (similar to tanker practices) | • confined spaces may contain flammable gases or asphyxiant nitrogen  
• more spaces are likely to be affected on a gas/LNG-fuelled vessel than on a conventionally fuelled ship |
| Deck-mounted fuel tanks and pipework | • lifting controls are required above fuel tanks (see section 7.14), equipment and piping because a gas/LNG leak from a dropped object has greater potential consequences |
5.4.2. Competency Levels

Worker competence is key. Existing working cultures need to change significantly to avoid the potential dangers of flammable gases becoming reality. The demonstration of competence is essential to establishing good practice.

Shipyards often use large amounts of casual labour on a subcontracted basis to meet peaks in workload. This may challenge the ability to ensure and demonstrate a competent workforce. The training and competence of the vessel crew that remain on board is also crucial.

Only qualified and authorised workers should be allowed in hazardous zones and safety-sensitive areas. Access control, as required by ISPS, is therefore more important. A capability to easily recognise which workers are competent is needed – perhaps through coverall or helmet colour, or some form of coloured epaulette or lanyard.

Eight categories of workers are identified:

1. all workers (including subcontractors), surveyors, inspectors, visitors and so on
2. workers in hazardous and safety-sensitive areas
3. workers in areas where escape is difficult – for example, crane drivers
4. managers/authorisers
5. first responders
6. second/third responders
7. gas/LNG engineers
8. chemists

Minimum competences for the first six roles are shown in Table 5.4. The two new specialist roles in categories seven and eight are described below. Supervisors should have the same or a higher level of competence as workers.
LNG/gas engineers with specialist knowledge about how LNG/gas behaves should be available, preferably employed, by both owner and shipyard to advise on all aspects of LNG-fuelled ships. The vessel’s chief engineer or his deputy may take on this responsibility, on behalf of the owner, or a specialised marine superintendent may be employed. These engineers should have the following competences:

- what personal protection equipment is required and how it is used
- hazards and risks associated with LNG/natural gas and their mitigation and control
- LNG and gas firefighting techniques and how these affect emergency response and evacuation
- the significance of hazardous zones and safety-sensitive areas and how to define and manage them
- what restrictions should be placed on electrical equipment, sparking tools and activities
- detailed knowledge of all special working practices and when/where to insist on their use
- how the permit-to-work system operates
### Table 5.4: Minimum competences

<table>
<thead>
<tr>
<th>Role</th>
<th>Competence</th>
</tr>
</thead>
</table>
| All supervisors, workers, surveyors and inspectors                   | • what personal protection equipment is required and how it is used  
• how to respond to emergencies such as a fire or gas/LNG leak, primarily through raising the alarm and evacuating via an approved route to a meeting point in a safe area  
• which areas they are not allowed to work in (for example, hazardous zones and safety-sensitive areas) |
| All supervisors and workers **in hazardous and safety-sensitive areas** | • what personal protection equipment is required and how it is used, including personal gas monitors and area gas detection  
• the hazards and risks associated with LNG/natural gas and how to recognise them  
• requirements for entry into hazardous zones and safety-sensitive areas  
• restrictions on electrical equipment, sparking tools and activities because of the potential presence of gas/LNG  
• how the permit-to-work system operates and its effects on working practices and personal behaviours  
• how to identify when multiple tasks are affecting overall safety and the need to report this back to supervisors/permit authorisers  
• where to find and how to use maintenance and calibration instructions provided by manufacturers of specific equipment items or ship’s systems |
| Workers in areas where escape is difficult                           | • crane operators should receive additional training in procedures for transiting hazardous zones and for no-fly zones  
• how to respond to emergencies                                                                                            |
<table>
<thead>
<tr>
<th>Role</th>
<th>Competence</th>
</tr>
</thead>
</table>
| Managers/authorisers | • what personal protection equipment is required and how to ensure it is available and correctly used by workers  
• how to respond to emergencies through the activation of contingency/emergency plans and the organisation of muster points  
• the hazards and risks associated with LNG/natural gas  
• how to identify staff competence and the suitability of staff for different work items in different locations – for example, in hazardous zones and safety-sensitive areas  
• how to identify outstanding worker training needs and how to arrange training to address them  
• when to supply and require the use of specialist (for example, non-sparking) tools for certain activities or locations  
• when to require the use of modified or specialist working practices for certain work items  
• how the permit-to-work system operates and its role in identifying interactions with other work tasks/areas |
| First responders (onboard the vessel/dockside) | • what personal protection equipment is required and how to use it, including personal gas monitors, safety lines and breathing apparatus  
• the properties of LNG and natural gas, particularly how they move and disperse  
• firefighting techniques for LNG and natural gas  
• how to treat cryogenic injuries, particularly burns, and asphyxiation |
| Second responders (in the dockyard) and third responders (public emergency services) | • the properties of LNG and natural gas  
• firefighting techniques for LNG and natural gas, particularly when and why water should not be used directly |
A suitably qualified chemist is needed to take atmospheric samples in the work area for analysis to confirm whether or not a flammable atmosphere is present. This chemist may be employed by the owner and/or shipyard, or be a third-party specialist, equally responsible to the regulators/authorities and the owner/shipyard. As well as a recognised qualification, the chemist should have the following competencies:

- what personal protection equipment is required
- how and where to take atmospheric samples for analysis of flammability
- which certified methods and techniques to use to analyse samples and the calculation methods applicable to reporting the results
- which equipment to use to analyse the gas samples and how to calibrate this equipment effectively before use
- how to assess and report sampling, measurement and analysis uncertainties
- how to respond to emergencies such as a fire or gas/LNG leak, primarily through raising the alarm and evacuating to a safe area
- the hazards and risks associated with LNG/natural gas and how to recognise them
- the requirements for entry into hazardous zones and safety-sensitive areas
- the restrictions placed on electrical equipment, sparking tools and activities by the potential presence of gas and/or LNG
- how the permit-to-work system operates and how it affects working practices and personnel behaviours

Many of the competences developed by SGMF for LNG bunkering can equally apply to workers maintaining gas-fuelled ships. For more information, refer to: “Gas as a marine fuel – Bunkering of ships with LNG – competency and assessment guidelines”, SGMF FP04-02, v2 2017”.
5.5. Risk Management

Planning and risk assessment will be effective only if the results of the risk assessment and all the mitigations are applied and the workforce follows the agreed precautions and working practices. This section covers risk management and the scope in the figure below.

A common approach to risk management is through a permit-to-work system, which is normally part of a vessel’s Safety Management System. A permit-to-work is the formalisation of a risk assessment. It should be used to apply and confirm the effectiveness of control measures. A permit identifies the wider risks and hazards and how they are dealt with. It also requires workers to follow all working procedures to ensure its effectiveness. If the vessel is not wholly gas-free, there will be additional hazards to mitigate. In addition, the consequences of a gas/LNG escape are likely to have greater impacts on crew and vessel than leaks of conventional fuel.
Both shipowner and Maintainer need to write permits for the work to be undertaken. Wherever possible, the permit-to-work regime should be harmonised between the vessel and the Maintainer. All activities need to be co-ordinated between all the parties involved. The job sheets will normally define which permits will be required.

When multiple maintenance activities occur simultaneously, more emphasis will be required on work planning because some work may need to be performed in specific time slots to minimise interactions with other activities. Workers should be instructed on when work can occur and should seek advice if their work extends beyond these times.

A permit should list the following:

- a description of the work
- isolations to prevent hazards occurring (both physical – for example, valves and circuit breakers – and managerial)
- how these isolations are proved – for example, lock number and supervision
- the mitigation methods employed – for example, signage and physical barriers
- the precautions to be taken by workers
- atmospheric test results (where required)

Ideally, a permit should require:

- hazards to be identified
- any work procedures or job safety analyses that support the work are identified
- the emergency equipment to be used or laid out ready for use
- what PPE should be worn
- the consequences and actions to be taken should something goes wrong

A permit-to-work is broken down into several tasks, as shown in the flowchart in Figure 5.4 and in Table 5.5, which defines how responsibilities should be distributed by owner and maintainer.
Figure 5.4: Permit-to-work flowchart

- Maintenance task required specified
- Safe working procedures produced
- Risk identification and assessment
- Maintenance mitigations put in place
- Isolations, draining, purging and gas atmosphere checks completed
- Permit completed and signed by owner
- Permit published and filed

- Supervision
- Periodic atmosphere checks (if required)

- Permit agreed and authorised (signed)

- Work execution
  - Work or environmental condition change?
    - Yes
      - Work suspension
      - Work extension
    - No
      - Work completion

- Permit signed off

- Supervision

Removal - roles and responsibilities of the owner are shown in blue, the maintainer in green, and joint actions in yellow.
Table 5.5: Permit-to-work responsibilities

<table>
<thead>
<tr>
<th>Permit stage</th>
<th>Owner</th>
<th>Maintainer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work area preparation</td>
<td>Make the system/area safe for the work to be undertaken by, where necessary, depressurising, draining, purging and isolating, and locking open or shut the appropriate valves and removing the necessary electrical breakers.</td>
<td>Brief the workforce on the preparations made and the importance of following them. Conduct a visual inspection and identification of the work area with owner representative</td>
</tr>
<tr>
<td>Appropriate working procedures, tools/equipment and worker training</td>
<td>Apply agreed working procedures and tools for the task, using staff with the required competences.</td>
<td></td>
</tr>
<tr>
<td>Risk assessment and authorisation</td>
<td>Permits need to be co-ordinated centrally so that all workers/supervisors know what is going on around their job site. Permits should be authorised by one individual representing the owner/manager and one from the Maintainer/worker. All permits should be authorised by the same individual(s), so that hazards associated with one task do not affect another, both spatially and physically through equipment, or via links to associated systems (for example, ventilation, power, air, cooling and so on). If job tasks do conflict, they should not be allowed to happen together. Hazardous zones and safety-sensitive areas may change on a daily basis as work is specified, performed and systems re-commissioned. The permit authorisers must have access to the latest drawings covering these areas and, where necessary, temporary changes to P&amp;IDs (Process and Instrumentation Diagrams) and ELDs (Engineering Line Diagrams). It may also be necessary to issue these drawings to supervisory staff and, in some instances, workers.</td>
<td></td>
</tr>
<tr>
<td>Permit stage</td>
<td>Owner</td>
<td>Maintainer</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Staff briefing</td>
<td>The owner may need to provide specialist advice about an equipment item, operating system or location to the authorisers and/or Maintainer to allow them to brief their workforce.</td>
<td>Those supervising and performing the work must be briefed by the permit authorisers on the hazards and any special working methods, procedures and equipment required.</td>
</tr>
<tr>
<td>Work performance</td>
<td>Review the performance of the Maintainer, providing support and insight where applicable.</td>
<td>The workforce must be supervised sufficiently to remain within the limitations of the permit.</td>
</tr>
<tr>
<td>Supervision and continuous risk review</td>
<td>Continuously review the work against the terms of the permit and against changing conditions in the surrounding work environment. Be prepared to stop or pause the work should a potentially unsafe situation appear or start to develop. A permit should last only one shift but can be renewed for future shifts by repeating the risk assessment and reconfirming that the isolations and precautions remain in place.</td>
<td></td>
</tr>
</tbody>
</table>
Permit systems for some types of vessel will need to be adapted for vessels using LNG/gas as fuel to recognise additional types of hazard. If the vessel is a tanker (oil, product, chemical or gas) many of these additions will already have been adopted.

Suggested additions to the permit-to-work system include:

- the potential for isolated liquid-filled systems to subsequently pressurise
- the potential for trapped gas pressure
- training, competence and/or briefing requirements for a specific job
- what cannot be taken into the job area (ignition sources, such as mobile phones)
- access requirements may need to be included on the permit, – for example, “don’t move this pipe”, “block this duct”, and so on

Many ships operate a two-tier permit system: ordinary permits and hot-work permits. The difference is primarily the level of risk assessment undertaken. This enhanced rigour is more appropriate to a gas-fuelled vessel and should be used whenever the work is in a hazardous or safety-sensitive area. For work in these areas, the following two points are especially important:

- permits must be authorised by appropriate individuals; for fuel systems and safety-critical systems, the owner’s specialist LNG engineer should review or authorise the permit
- supervisors of maintenance work should also sign the permit to ensure that they understand the work and its implications and can therefore communicate requirements to the workers

An example of a permit suitable for use on a gas-fuelled vessel is shown in Figure 5.5.

Permit-to-work systems for maintenance activities appear to work well at the planning stage but perform less well at the job site. The permitting process is effective; the main issue appears to be in implementation through poor briefing and supervision of individual workers (or work groups). Failings appear to be on both the yard and owner sides.

- yards need to brief and supervise workers more effectively.
owners need to monitor work more fully and provide additional briefings when work is in hazardous or safety-sensitive areas.

- specialist LNG/gas engineers from both owner and Maintainer may need to supervise specific procedures.

A lack of supervision may allow poor behaviours to develop or continue in use.

Unless the repair and maintenance works are very modest, it is unlikely that the vessel’s safety officer will be able to perform all the safety supervision alone. Roving patrols by ship staff should monitor work and supervise activities for both quality and for safety.

The vessel can help to make this process more effective by enabling more ship officers to support yard work by minimising, or not assigning, any work tasks of their own. Safety issues should be addressed immediately and directly with the individuals involved. The vessel safety officer, on being informed, should decide whether any safety inadequacy should be escalated to higher managerial levels.

Similarly, the yard safety advisor should act as a focal point for poor safety behaviours by those maintaining the vessel. He/she should check work personally but also rely on each work supervisor who should be addressing all safety issues immediately and directly with the workers involved and reporting those poor behaviours for improvement. This may include for example, not following a required procedure or use of the wrong tool.

A good practice permit system would see:

- supervisors (who apply the permit) briefing the workers on what to do and providing them with all the tools and conditions to work safely after the work permit is approved. The supervisor signs the permit on behalf of the workers.

- workers signing the job brief sheet after the toolbox talk by the supervisor to acknowledge that they have understood and will comply with the scope of the work, the precautions required, and the working methods and standards expected.

It is essential that the work permits are all returned at the end of a shift so that the next shift understands the current situation.
Figure 5.5: An example of a permit suitable for use on a gas-fuelled vessel
Notes on Figure 5.5: An example of a permit suitable for use on a gas-fuelled vessel

1) Work Description and Location
What is the work and where is it.
In this case: “entry into a tank storing hydrocarbon to re-weld a seam after grinding out with an electrical tool in tank S27 in the MRS tank farm”.

2) Isolations
What systems need to be isolated and how has this been achieved?
Where valves (both manual and actuated) and electrical circuits need to be formally isolated (lock-out/tag-out procedure) the number of locks used to prevent accidental reinstatement should be recorded.
In this case: valves V8 and V9 locked shut after the tank has been drained and a blank flange applied. Tank heating system (steam) is isolated at valve V2, which is locked shut. Nitrogen supply to the tank is locked shut and, for additional safety, the pressure-relief valve PRV27 is removed. The project initiator has signed each isolation as being in place.

3) Purging
Ensuring that the atmosphere is non-flammable.
In this example: the tank has been cleaned with steam to remove hydrocarbon vapours and then purged with air for at least 24 hours. The completion of purging has been signed off.

4) Precautions
The list of additional precautions required, in this case the use of a checklist. Here, the following are required:
No smoking, lighters, matches (and mobile phones). Signs to be erected.
One person to be outside the tank as an observer.
Flameproof overalls, eye and ear protection to be worn. Breathing apparatus to be laid out. Personal gas monitor to be worn.

5) Atmospheric Tests
Despite purging, the atmosphere should not be deemed safe unless it is monitored.
In this case: two portable flammable gas meters are issued and both checked for calibration and function.

6) Declaration
The individual preparing the work declares that all the precautions to mitigate hazards are in place.

7) Authorisations
Permit authorised by the job owner and the manager issuing the permit. Permit has been renewed once.

8) Acceptance by Workers
Each worker and his/her supervisor have signed that they understand the work.

9) Suspension for Testing
To test that a system has been repaired successfully, the permit may need to be temporarily suspended. This suspension may introduce the original and new hazards and must be authorised. Compatibility with other tasks and permits also needs to be evaluated.

10) Extension/Renewal of Permit
Permits should last only one shift and need renewal if they are to be passed on to a second shift. This renewal should be authorised only if all the isolations and precautions remain in place and the staff taking over the work are briefed on the permit requirements.
It is good practice to only renew a permit once.

11) Clearance/Cancellation
When the work has been completed to specification and approved, the isolations and precautions can be removed and the permit signed off as completed.
5.6. Contingency Planning and Emergency Response

Contingency plans must be made to allow effective emergency response should control measures fail and an event occurs which requires immediate action.

The following events that need to be examined are common to all ships:

- injury/medical emergency
- asphyxiation in a confined space
- fuel leakage
- damage from a dropped object
- fire

However, the use of gas/LNG as fuel requires the addition of the following:

- gas venting
- cryogenic embrittlement of the vessel’s hull
- cryogenic injury
- LNG/gas leaking, causing a potentially flammable gas cloud
- LNG spill forming a pool
- explosion

A separate gas alarm warning (audible and visible) may be used. This allows different actions to be taken in different scenarios. However, it is more important that workers escape immediately and, if necessary, are then subsequently redirected by QHSE/HSEQ specialists. Multiple escape routes are beneficial, allowing prioritisation and signing on the vessel – but the physical size of the vessel and, if in a shipyard, its location may make this impossible.

- evacuation and escape plans need to be used whenever a gas (and/or vaporised LNG) leak is detected. As gas travels some
distance in the direction of the wind, the location of muster points may need to change daily to ensure that the muster point remains safe; it should be located up wind of possible leaks. So escape routes must be clearly marked.

- work must not be allowed to restart until the cause of the gas alarm has been determined, corrective action taken to stop any leak, and all spaces where gas may have leaked into checked and declared safe.

All workers and supervisors must know how to raise the alarm and what to do when an alarm is heard/seen.

Emergency response requirements are also different, requiring different firefighting techniques and equipment. For example, attempting to fight a LNG fire with water is counterproductive as the water supplies heat, vaporising the LNG faster and thus enlarging the fire. Fighting LNG and gas fires is difficult; the only certain technique is to stop the fuel leaking by isolating the LNG/gas supply. The aim of firefighting if gas and/or LNG is involved is to prevent escalation to other systems which could fail as a result of the heat radiating from a fire, adding additional fuel and/or causing more damage.

Venting of gas to the environment from the vent mast normally produces lower levels of concern as the vent mast is designed to minimise the impact of the escaping gas on the ship. However, in a shipyard there may be cranes working overhead, which will have spark-producing motors and controls, and potentially buildings nearby, which gas may enter – both situations could lead to escalation of the emergency. During maintenance, gas may leak or vent from other locations, such as valves inadvertently left open or pipelines cut into by mistake. These leaks at physically lower levels present much more danger as they are closer to the workforce and could be sucked into the ship or buildings through ventilation systems or open doors/hatches.

Containing LNG spills is only possible if the likelihood of a spill is anticipated and a drip tray put in place. LNG spills can last for minutes up to a few hours (depending on scale) as the heat transfer from a metal
to vaporise the LNG is a relatively rapid process. Gas will be present with every LNG spill and dense gas clouds are both asphyxiants and quickly limit visibility. So evacuation of workers to a safe place must be immediate.

5.7. Reporting and Auditing

5.7.1. Reporting Requirements
Competent authorities, be they Flag States of the vessel or local authorities governing shipyards, authorise the maintenance processes and may impose limitations on what is allowed and what needs to be reported to them.

- LNG on board should be reported.
- the vessel or shipyard have to report that the LNG monitoring system will remain constantly operational, and that the LNG fuel tank atmosphere management system will be able to control the pressure in the bunker tanks during the stay at the dockyard.
- if the LNG monitoring system or the LNG fuel tank atmosphere management system will be out of order, the vessel or shipyard have to report what alternatives will be used to manage the pressure in the tank.
- if pressure management is unavailable, the following should be reported to the authority:
  - the quantity of the LNG in the fuel tank
  - the temperature and pressure of the LNG in the fuel tank
  - the opening pressure of the PRV valve
  - the calculated holding time before the opening of the PRV
  - maximum duration of the stay at the dockyard

Reporting may be procedural, for example, “the vessel arrived on a date with a fuel tank with a pressure of x bar (below the limit of y bar)”, or responses to significant events that occur during the maintenance process, for example, “liquid trapped in x pipework vaporised and actuated the TRV
resulting in \( y \) kg of gas being emitted to the environment”.

The vessel or dockyard should report significant events that occur during the maintenance process to the competent authority. This includes but may not be limited to:

- a problem that impacts any structural element in the LNG storage or gas supply system (pipe supports, bulkheads, saddles and so on) or impacts a surrounding area not covered by a hazardous area classification
- a delay which impacts the effectiveness of the BOG/tank pressure-management plan
- any injury or fatality
- a confirmed gas detection or venting of gas

Competent authorities should conduct inspections where they have concerns (policing the licensing process) but only stop the work if concerns are not relieved.

5.7.2. Third-Party Certification

There are two areas for consideration:

- yards may find it helpful to comply with certain international standards, particularly if compliance is audited and confirmed by an independent body. These standards are primarily about the implementation of management and work processes across projects and employees – for example:
  - ISO 9000 on work quality
  - ISO 14001 on environmental performance
  - OHSAS 18001/ISO 45001 on occupational health and safety
- these processes may be beneficial to shipowner, Maintainer and shipyard but are unlikely to specifically recognise the type of fuel on board.
- the need for specific staff or independent inspector skills – for example, a certified chemist (often known as a “gas doctor”) – who
can demonstrate appropriate qualifications and, more importantly, the training and competence to fulfil this role.

As international standards are largely generic, it is unclear whether such an independent audited process would provide any additional value for gas/LNG-specific tasks over normal shipyard processes.
6. Maintenance within Shipyards and Dry Docks

This section builds on Section 5 by taking the general concepts applicable to all maintenance tasks and interpreting them in more detail for use within shipyards and dry docks.

6.1. Regulatory Requirements Covering Shipyards

Shipyards are regulated by national and local regulators.

Most shipyards have to submit documents to their competent local/ national authorities to be allowed to operate – both generally and for specific purposes. It is not always clear which is the competent authority. In most cases, the yard’s regulator will be the onshore safety body (for example, the enforcer of the Seveso directive 96/82/EC in Europe).

Table 6.1: Examples of competent authorities

<table>
<thead>
<tr>
<th>Country</th>
<th>Maritime authority for vessels at sea and in port</th>
<th>Construction and repair authority for vessels in dry dock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td>Finnish Transport and Communication Agency (TRAFl)</td>
<td>Finnish Safety and Chemicals Agency (Tukes)</td>
</tr>
<tr>
<td>France</td>
<td>DAM/Sous-direction de la sécurité maritime</td>
<td>DAM/Sous-direction de la sécurité maritime (ships)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DGPR /DREAL Service des risques technologiques (dry dock)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ministère du travail</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Inspectie Leefomgeving &amp; Transport (Flag state)</td>
<td>Environmental agency</td>
</tr>
<tr>
<td></td>
<td>Port authority</td>
<td>Inspectie SZW (labour inspection)</td>
</tr>
</tbody>
</table>
As can be seen from Table 6.1, there are many different ways that competent authorities are organised and there is little consistency. Mostly, national systems are in place but these can be modified by local entities such as port authorities.

Competent authorities will understand in detail how shipyards work but may not have specific knowledge of low-flashpoint fuels unless local yards have a track record of handling gas carriers (LNG, LEG and/or LPG) and have allowed these vessels to be maintained with gas (as cargo) onboard.

For example, one authority required that tanks are empty of fuel (conventional and gas-as-fuel) and that the atmosphere inside the tank must be at or lower than 50% LFL. Only in 2006 were these restrictions on conventional fuel tanks relaxed.

While competent authorities have limited knowledge, it is likely that there will be resistance to having gas onboard while in a shipyard.

<table>
<thead>
<tr>
<th>Country</th>
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</thead>
<tbody>
<tr>
<td>Norway</td>
<td>Norwegian Maritime Authority</td>
<td>Norwegian Directorate for Civil Protection (DSB)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arbeidstilsynet</td>
</tr>
<tr>
<td>Singapore</td>
<td>Maritime and Port Authority of Singapore</td>
<td>Ministry of Manpower Major Hazards Department</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ministry of Manpower</td>
</tr>
<tr>
<td>South Korea</td>
<td>Ministry of Oceans and Fisheries</td>
<td>Ministry of Trade, Industry &amp; Energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ministry of Employment and Labor</td>
</tr>
<tr>
<td>Sweden</td>
<td>Transportsyrelsen</td>
<td>MSB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arbeidsmiljövärvet</td>
</tr>
<tr>
<td>UK</td>
<td>Marine &amp; Coastguard Agency</td>
<td>Health &amp; Safety Executive</td>
</tr>
</tbody>
</table>

As can be seen from Table 6.1, there are many different ways that competent authorities are organised and there is little consistency. Mostly, national systems are in place but these can be modified by local entities such as port authorities.
The primary concern of competent authorities is to protect the public from being harmed by activities within the yard (including an LNG-fuelled ship with fuel onboard) – typically to a risk level of less than 1 in a million ($1 \times 10^{-6}$).

The safety of workers in the shipyard and the ship’s crew may be under the same body or a second onshore regulator. (Risk to workers can be at a higher level, typically $10^{-4}$ to $10^{-3}$). The yard should demonstrate, using risk assessment, which levels of harm are within regulated limits. The yard will also be responsible for ensuring that all activities meet the environmental discharge criteria of its location. Some form of auditing process of the yard by the competent authority can also be expected.

Shipyard workers are primarily governed by onshore rules (for example, Seveso in Europe) and therefore these rules may apply if the ship enters a shipyard – but this depends on the attitudes of local authorities.

If fuel (both LNG and gas) transfer to and/or from the vessel is required (for example, bunkering or gassing up), this will require the shipyard to obtain a separate licence.

In many jurisdictions shipyards will require additional regulatory acceptance if a gassed-up vessel is to be maintained. This reflects both the embryonic nature of the IGF Code and the number of ships involved, as well as the potential additional hazards posed by quantities of volatile fuels. If a shipyard is not regulated to operate on a gassed-up vessel, then the gas may need to be removed from the fuel tanks and replaced with a non-hazardous atmosphere.

### 6.2. Competent Authority Approvals

The management procedures for the maintenance, safety and environmental performance of a shipyard should be approved by competent authorities at a local/national level – as part of the periodic licensing of the shipyard for operation – and should conform to rules, regulations and legislation.
These rules, regulations and legislation differ around the world. For example, at the time of writing:

- in Europe the Seveso directives apply only to fixed infrastructure, meaning that the vessel itself is not covered. However, if the vessel interacts with any land-based LNG equipment – for example, by transferring LNG – then the Seveso directives may be deemed to apply to the ship and a special licence may be required.
- if a bunker vessel is used to transfer LNG, the bunkering licence should cover this activity at this location.
- Regulations at the Port of Rotterdam in the Netherlands allow vessels with LNG fuel onboard to enter shipyards. So do the regulations in Finland – but not in Singapore.

That said, most rules are based on generally agreed practices developed on an international basis and then subsequently adopted and modified for local use.

**Example**

One vessel entered a European shipyard with LNG onboard to complete commissioning of the owner’s equipment. The shipyard was able to accept the vessel in this condition for this work. The vessel was bunkered during its stay using a bunker vessel, which again was permitted under the bunkering licence after mitigation of SIMOP activities. Following risk assessment, and after a training course for the shipyard’s personnel, bunkering by road tanker was also permitted.

A competent authority can be expected to want answers to the following questions:

- is there an accepted plan in place (normally a pressure-management plan) to stop fuel being spilt/lost or its vapour vented to atmosphere during the maintenance activity, with the potential to ignite, causing a fire and/or explosion?
• is there an accepted plan in place to stop fuel being spilt/lost or its vapour vented to the atmosphere during the maintenance activity, leading to emission of greenhouse gases (CO₂ and/or methane) to the atmosphere?

• are there contingency plans in place to deal with these two scenarios should the accepted management plan fail?

• are there contingency plans in place to deal with accidental damage (due to other repair activities) to LNG containment or gas lines during the course of the dry-dock period?

• are the yard’s first responders suitably equipped, trained and competent to work on incidents involving cryogenic and warm spills of natural gas/LNG?

• are there sufficient local emergency responder resources (fire, medical and so on) available to implement the contingency plan should it be required?

• are yard personnel trained and competent to work on LNG-fuelled vessels, including whether the yard employs or has access to a specialist LNG/gas engineer?

• will bunkering, de-bunkering or any other form of LNG/gas transfer, on or off the vessel, take place and how will this be managed?

A competent authority may also wish to know:

• the volume of LNG in the closed fuel tank system to ensure compliance if the amount of hazardous material in the yard’s licence is limited.

Typical competent authority approval considerations are shown in Figure 6.1.
6.3. Additional Facilities/Equipment to Implement the Gas Pressure-Management Plan

The “emergency” options available to a shipyard should the shipowner’s approach fail are essentially the same as the owner’s but must be provided in a limited timescale. Depending on how failure is defined (the agreed time/pressure margin), the equipment must therefore be already installed or immediately available for deployment.

The control methods that a shipyard might employ include:

- evacuation of staff and controlled venting through the ship’s vent mast
- controlled venting through temporary pipework that links the vent
mast/vapour return pipework to some remote facility/location

- ignition of venting gas at some remote facility/location
- emergency decanting (de-bunkering) to remove some of the LNG to a road tanker or temporary tank for disposal offsite

Note that spraying is used when bunkering to homogenise the tank temperature, which can result in a collapse of tank pressure. This is most effective in Type C tanks as other tank types have a limited pressure range. However, this is only effective over the short term because once the top and bottom temperatures are the same no further cooling (and consequently pressure reduction) takes place.

Whichever options are selected, they need to be clearly defined and explained through standard operating procedures and incorporated into vessel/shipyard manuals, job plans and other relevant documentation – and approved by the competent authority.

The gas-management plan is likely to need additional equipment, supplied either by the vessel or by the shipyard.

The following equipment, whether owned or hired by the vessel’s owner or the shipyard, may be needed to perform the maintenance work:

- access for LNG road tankers or trucks carrying ISO containers to remove surplus LNG fuel to the dry-dock/maintenance area
- a skid-mounted thermal oxidiser or gas combustion unit (GCU) to burn off surplus gas safely and a means of safely connecting this to the vessel’s systems
- a connection from the vessel to a gas grid within the shipyard which is able to dispose of the gas through a centralised GCU or use it as fuel for other systems – for example, power generation or conversely to supply fuel to shipboard systems when the ship’s own gas supply is out of service, such as during commissioning (note that public gas distribution systems have onerous gas quality and odorisation requirements which a temporary fuel supply is unlikely to comply with without significant investment)
• a skid-mounted (LNG) BOG re-liquefaction plant to cool, liquefy and return LNG via a temporary piping system to the vessel’s fuel tanks
• a power supply to operate additional equipment, such as a re-liquefaction unit, or critical ship systems in the process of being maintained
• services (for example, cooling water, electricity and so on) supplied by the yard to operate items of vessel equipment (such as a GCU, a boiler or engines) or shipyard temporary facilities (such as a flare or re-liquefaction unit) should be independent and sufficient to ensure that the gas management plan will work
• a bulk supply of nitrogen in gaseous form for purging and warming
• access to liquid nitrogen for purging and cool-down of LNG systems, particularly fuel tanks, probably through access for liquid nitrogen road tankers to the dry-dock/maintenance area
• a vaporisation system for liquid nitrogen (LIN)

6.4. “LNG-Ready” Dry docks

This guidance introduces the concept of an “LNG-ready dry dock”. This “LNG-ready” process should benefit the vessel owner by providing more certainty that tender specifications, skills and procedures are all in place and visible. It should also assist with licence applications to competent authorities, if these are needed.

A “LNG-ready” dry dock is:

A shipyard that has plans, enhanced skills, equipment and management systems in place to be competent and able to handle gas/LNG-fuelled vessels with fuel (gas/LNG) onboard

The additional plans, procedures and equipment should include:

• an LNG/gas specialist:
  ○ employed or subcontracted to the yard and in the yard when the vessel is present
if required by local regulatory bodies, an independent third party to lead or audit QRAs/HAZIDs/risk assessments and define the control and preventive measures to be implemented in the shipyard

- trained and competent personnel, in both management and operations, who:
  - understand the behaviour of LNG/gas and the different hazards of LNG/gas compared with liquid fuels
  - understand the implications of gas hazardous and safety-sensitive areas

- a permit-to-work system and effective worker communication systems, updated at least daily and preferably each shift (or each change of staff), which have a combined view of both yard and vessel activities/permits, thereby ensuring effective co-ordination between the shipyard’s staff and the owner’s ship crew/superintendent. These meetings should:
  - confirm what work will take place, how and where
  - review risk assessments and their implications, which should be reflected in any permits
  - confirm the necessary mitigations – for example, isolations (lock-out/tag-out) – are in place
  - confirm that contingency plans are in place – for example, appropriate firefighting and rescue
  - cascade this information effectively to workers and supervisors

- the ability to assess the quality of subcontractors (including LNG/gas specialists) and, if necessary, impose “LNG-ready” behaviours and working practices.

- an understanding of gas-detection technology and its use.

- standard procedures, modified appropriately for working on and around gas/LNG-fuelled ships. These should cover:
  - positive isolation of safety, electrical and fuel/gas systems
  - hot work, including earthing requirements for welding
- equipment and pipeline identification
- maintenance of electrical equipment certified for hazardous areas (more complicated because it is dispersed throughout the vessel)
- control of personal equipment (phones, smoking paraphernalia, and any other electronics not compatible with gas hazardous areas)
- hazardous (and confined) space entry (similar to tanker practices)
- control of access to hazardous and safety-sensitive areas
- storage, handling and working with exotic materials (for example, stainless steel and aluminium) and the impacts of work processes (for example, carbon steel grinding or weld splatter) on them
- cleanliness and housekeeping
- moisture ingress control
- lifting controls above fuel tanks, equipment and piping
- cryogenic insulation
- pipe support for cryogenic service (capable of handling expansion and contraction)
- welder qualifications
- evacuation and mustering procedures
- access to suitable facilities to store, handle and work on cryogenic equipment and materials (for example, clean rooms).
- an understanding of the interactions of works on multiple vessels (SIMOPs) on the gas-fuelled ship – for example, the use of double-banking as to whether this is possible or in which order ships need to be moored to limit access of personnel to restricted areas but to maximise emergency response capabilities.
- appropriate locations for LNG-fuelled ship maintenance, taking account of the needs of other ships and of the proximity of hazardous materials (such as stores of welding gas) elsewhere in the yard
- assessment of the readiness of the shipyard and local fire brigade to deal with emergencies and/or participate in common drills.
• a demonstration that, for each specific ship, the shipyard planning has considered all the points in Section 6.4.

The shipyard should self-assess its capabilities against the “LNG-ready” requirements in such a way that owners and competent authorities can review the information against their requirements.

Competent authorities are encouraged to review and grant permissions based on the “LNG-ready” criteria.

6.5. Shipyard Planning

Once a scope of work has been agreed, the owner and shipyard should plan for the arrival of the gas-fuelled vessel. The yard will use risk assessment to review the scope of work and set the necessary precautions. Additional risk assessment will be required if the scope of work involves maintenance of any of the following:

• LNG fuel tank valves, sensors or gauging systems
• the heating system (such as glycol) that conditions the LNG/BOG before consumption
• LNG and gas lines and valves
• the tank insulation system
• ventilation or purging systems for LNG lines or spaces
• gas or cold detection systems
• LNG control or safety systems
• firefighting or fire suppression systems that are out of service or have reduced capacity

Based on the risk assessment, the following factors should be considered:

**Hazardous zones**

A scale drawing of the gas-fuelled vessel, showing hazardous zones and safety-sensitive areas, must be supplied by the owner for review by the
shipyard. Using this review, the shipyard should plan the location of the vessel, both alongside and in dry dock, by overlaying the hazardous zone drawing of the vessel onto the docking and/or mooring location to ensure that, whenever possible, the integrity of the hazardous zones is maintained. If there are any ignition sources within the hazardous zones, the proposed work location should be changed or the ignition sources removed or rendered incapable of igniting fuel. The following factors should be considered:

- whether any hazardous zones go beyond the physical limits of the vessel and need to be enforced by other means
- in dry docks hazardous zones may be below the edge of the dock so the appropriate areas on the dock side and in the base of the dock should be sectioned off.
- power connection boxes and other utilities must be located outside of hazardous zones. Where this is not possible, such connection points must be inspected to ensure they are in good condition and isolated/de-energised. Lock-out/tag-out should be used to prevent inadvertent reactivation while the vessel is at the berth.
- suction for air compressors should be situated outside hazardous zones.
- diesel-fuelled and other combustion engine-type generators should be outside hazardous zones. If that is not possible, they should be disabled.
- before berthing, cranes should be situated in the best position to serve the vessel while minimising the need to enter or transit through hazardous zones – for example, the vent mast or safety-sensitive areas. Temporary crane stops may be needed to prevent accidental movement through a hazardous zone.
- lighting towers and portable lighting systems must not be located in or above the hazardous zones unless they are specifically designed to not ignite flammable gases.
- operations such as shot blasting and painting that can generate static electricity should not take place in hazardous zones without precautions being taken to prevent ignition of flammable gases. For this reason, hydro-blasting is better than grit blasting.
• static charges can be generated by weather conditions just before rain. So it is important to ensure good ventilation in a hazardous area.

• if the vessel requires welding to its steel structure, the entire hull should be grounded to the shore’s earth sink. The connection of the earthing plate can also generate sparks when the welding sets are activated on each arc strike. So both the location and type of the earthing point onboard, and one that is added with a shielding cover, are important.

• worker access to and from the vessel should not pass through or over hazardous zones.

Working plans and procedures
Consider – using the scope of work and layout of the vessel – whether any changes will be needed to a shipyard’s standard operation procedures and method statements for gas-fuelled vessels and for a particular vessel. Examples of method statements that might need modifications include:

• access control systems to hazardous zones and safety-sensitive areas, such as the LNG tank space
• arrangements for how LNG and gas systems are isolated and locked/tagged out
• the compatibility of yard and owner permit-to-work systems
• any configuration and spatial issues concerning work on gaseous fuel or nitrogen systems
• arrangements for alerting workers to unsafe or abnormal events, such as gas detection, either automatically or through the monitoring of vessel safety systems by its crew
• how evacuation routes and temporary refuges (if any) are signed and communicated

Contingency plans
The owner of a gas-fuelled vessel should supply a fire and safety plan for review by the shipyard. Using this plan and its own risk assessments of the work involved, the shipyard should implement contingency
planning. Such planning is required in at least three areas: failure of the gas pressure-management plan, workforce protection, and response to emergency incidents.

**Planning for failure of the gas pressure-management plan**

- the owner should supply, for review, a tank pressure-management plan that will prevent a vessel venting gas in the shipyard. The yard should not be responsible for failure of the owner’s BOG management plan unless this was the result of the yard’s failure to supply an agreed utility, for example cooling water.

- At the request of the vessel’s owner, the shipyard with sufficient time to allow sourcing and implementation, provide additional equipment, materials, power, connections and so on, to either prevent the pressure exceeding the Maximum Acceptable Pressure (MAP) or to mitigate the consequences when the LNG tank pressure does exceed MAP through alternative gas disposal means – for example, by deploying a portable flare or gas combustion unit.

- In a dry dock, a vessel should be positioned so that its departure is not prevented by delays to work on any other vessel in the dock which cannot be re-floated.

- should the plan involve removing LNG from the vessel or bunkering – provided this is allowed by the yard – approved bunkering procedures with a safety check-list should be provided and agreed (see SGMF’s bunkering guidelines).

- the ideal arrival condition of the LNG tank should be defined, based on the expected time in dry dock and the nature of the work being planned. This will provide the theoretical time before pressure-management actions are required.

- the plan should set out the actions a vessel should take if the pressure in the fuel tank exceeds the limits in the management plan and gas venting has begun or is imminent.

**Planning for workforce protection**

- the shipyard should develop contingency plans to detect – and protect the workforce from – any gas leak or LNG spill that occurs during or as a result of maintenance work.
• if primary safety and monitoring systems – such as gas detection – are not operational due to maintenance, there should be alternative means of monitoring gas/LNG and related systems.

• the plan should specify any training, PPE, special tools (such as intrinsically safe/EX-rated tools) and procedures that may be required.

Planning for response to emergency incidents

• emergency incident plans should be developed to handle any fires and explosions that result from gas/LNG leaks. These should make clear what the vessel should do and what the yard should provide.

• an “emergency response compatibility check” should be performed to ensure that the yard’s firefighting system is compatible with the capabilities of the vessel while it undergoes maintenance.

• provisions should be in place to mitigate any reduction in the capacity of the vessel’s firefighting and water deluge systems.

• the plans should consider the implications for other vessels of a failure on one ship cascading to others – particularly if double-banking is planned. Likewise incidents on these other ships may effect the gas-fueled vessel or be a catalyst for a failure on it.

• the local authority emergency services should be contacted and briefed on: the nature of the activities taking place; the amount and location of any gas/LNG onboard; and the expected duration of the vessel’s stay. This will enable them to consider their own emergency planning options. Dedicated contacts are preferable.

• appropriate drills should be conducted.

Gas use and bunkering

If LNG or gas needs to be removed from or bunkered to the vessel during the maintenance period, this should be confirmed by the owner before the dry-docking slot is booked. The shipyard can then proceed to get authorisation for these operations.
Four processes may require additional regulatory scrutiny:

- bunkering – supplying fuel to the vessel
- de-bunkering – removing fuel from the vessel
- tank pressure-management control – using the shipyard’s equipment rather than the ship’s to relieve excess pressure in the vessel’s fuel tanks
- cooling down and gassing up a fuel tank using nitrogen and/or LNG supplied in bulk in excess of the levels in the shipyard’s operating license.

SGMF has provided guidance on bunkering in “FP07-01 safety guidelines, bunkering”, which covers all these operations.

Of principal concern for these operations will be:

- the operational status of the safety-management system and any additional monitoring proposed
- the nature and extent of checks and inspections (for example, ensuring the system is purged with nitrogen and its leak-tightness) before hydrocarbons are introduced
- precautions during the gassing-up/liquid-transfer/commissioning processes, including inspections, leak checks, additional gas detection, flow rate limits and so on
- limiting the number of individuals involved to only the approved personnel, as described in SGMF’s “FP04-02 Bunkering of ships with Liquefied Natural Gas (LNG), competency and assessment guidelines”

### 6.6. Pre-Docking Information Requirements

A shipyard may need to demonstrate to the competent authorities that the vessel and proposed works are covered by its existing licence.

Key to this will be demonstrating that the emergency/contingency
management plan for tank pressure-management is appropriate. The shipyard will therefore need to judge the credibility of the shipowner’s BOG management plan – before the vessel arrives at the yard – by reviewing its operation and potential effectiveness, based on the proposed works. The yard may need to take measures to restrict the access/working zone around the vessel to a safe area, and/or obtain licences for use of yard cranes and other equipment inside this zone.

It is considered good practice on LNG vessel projects for the vessel’s owner and the shipyard to carry out a risk assessment, which may contain a HAZID or HAZOP, on the scope of proposed work before the vessel arrives at the yard.

Together with the owner, the yard will develop an HSE “bridging document” to define and control interfaces which at a minimum, will require the owner to provide the following information about the vessel design and procedures and its condition immediately prior to its arrival:

- emergency (24/7) contact numbers.
- a material safety data sheet (SDS), or an equivalent, for the LNG onboard.
- resubmission of the vessel’s gas-management plan on arrival, confirming the original plan and including the latest information regarding:
  - expected arrival and departure conditions, including tank level and status of LNG and gas systems (purged or under gas)
  - the BOG rate
  - the agreed check-list
  - measurements of tank level, temperature and pressure 24 hours before arrival to confirm expected arrival conditions
  - the fuel tank design including:
    - the tank volume,
    - the PRV pressure (MARVS),
    - the type and status of the tank insulation
close to the dry-docking date, the vessel’s engineering management team should carry out any activities needed to ensure that the condition of the LNG tank on arrival will conform with that stated in the dry-docking plan. These activities may include running gas-consuming equipment to reduce tank volume and pressure or perhaps arranging to bunker or de-bunker LNG just before the dry-docking date.

the arrival condition, as calculated and stipulated in the project planning phase, must be met before the vessel enters the dry dock. Otherwise, extra work will be needed to evaluate the impact on the dry-docking plan of the changed condition of the LNG tank when the vessel arrives.

confirmation that the safety and control systems required to maintain the integrity of the fuel supply and containment systems will be operating effectively throughout the maintenance work; or, if they too require maintenance, confirmation that the plans and procedures to be used will provide the same level of safety and environmental protection as the normal system (for the yard’s review and acceptance).

actions to be taken by shipyard staff should a vessel alarm activate.

how the LNG and gas system are to be protected against inadvertent/accidental operation/activation while at the shipyard.

how access to hazardous and safety-sensitive areas on the vessel will be controlled and the entry procedures for conducting work.

actions to be taken by the vessel in the event of a power failure/blackout while in the dry dock.

that a qualified chemist has been engaged to certify that systems/equipment required to be entered for maintenance are gas-free – for example:

- LNG- and gas-fuelled piping, including the LNG bunker station, are free of hydrocarbons
- LNG vent masts are free of hydrocarbons and tank safety valves are not flowing gas
- tank and/or connection spaces are free of hydrocarbons
• gas detection systems are operational.
• the vessel owner’s [safety] control philosophy, including:
  o a system overview/description
  o hierarchies
  o alarms
  o interlocks
  o by-passes
  o P&IDs
  o where isolations can be made
• the expected duration of the stay in dry dock (note that this may require some input from the shipyard).
• work needing to be done by the yard and any skill levels or specialised/additional equipment and materials that may be required.
• work to be done by the shipowner’s contractors or crew during dry-docking.
• any additional information needed by local/national authorities and regulators.
• briefing for supervisors and managers about, as a minimum, the ship’s emergency plan.
Example: Owner’s Requirements at Dry-Docking
(Type C LNG fuel tanks)

I. Before the vessel enters the dry dock the tank pressure should be reduced to 2.75 bar or lower. This is accomplished by running gas-consuming equipment on BOG while by-passing the pressure build-up evaporator (PBE), if any.

II. While the vessel is in dry dock, the LNG tank should be monitored and plotted every two hours to calculate the rate of pressure increase (boil-off rate).

III. When the LNG tank reaches 6.9 bar, gas-consuming equipment should be started and put in gas mode without use of the PBE.

IV. A fire hose should be rigged on the dry dock adjacent to supply cooling water to the gas-consuming equipment and the ship’s glycol system for LNG vaporisation.

V. Hot work in or near the ship’s hazardous zones will be allowed only after it is confirmed that all gas systems have been shut down and proper atmospheric testing has been completed. The atmosphere should be tested every four hours and the results recorded on the permit.

The owner of a vessel will require the following information from the shipyard:

- a single contact person (or an organogram that makes responsibilities clear)
- what services, particularly any additional services, will be available from the yard
- confirmation that a suitable dock/quay will be available
- the sequencing of work and how SIMOPs will be handled
- signals for alarms – for example, in the event of fire or evacuation – and what actions should be taken, such as the location of muster points (the emergency plan)
- the permit-to-work system to be used on board to allow the development of compatible and comparable systems in the yard
6.7. Roles and Responsibilities

Attempts by vessel owners to place all responsibility for risk assessment and work management on shipyards have proven unsuccessful. Legal judgements have always apportioned some blame to the shipowner or its representatives. If the supervisory staff on the vessel’s crew do not challenge specific working practices, they have been assumed to have understood the risks and accepted them.

The respective roles and responsibilities of a vessel’s owner and the shipyard are described in Table 6.2.

Table 6.2: Roles and responsibilities

<table>
<thead>
<tr>
<th>Role</th>
<th>Shipyard</th>
<th>Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Managers/vessel officers and senior technical staff</td>
<td>Develop and implement the yard’s safety framework, including working practices, training, contingency planning and emergency response.</td>
<td>Develop and implement the vessel's safety framework, including working practices, training, contingency planning and emergency response. Monitor the temperature and pressure in the vessel's fuel tank and track this against the gas-management plan, immediately communicating any changes/discrepancies to the yard.</td>
</tr>
<tr>
<td></td>
<td>Ensure sufficient resources are available for the safety framework to be effectively implemented and monitored.</td>
<td>Ensure the communication of hazards, mitigations and staff behaviours across all personnel and reinforce this through operation of the permit-to-work system.</td>
</tr>
<tr>
<td></td>
<td>Ensure the communication of hazards, mitigations and staff behaviours across all personnel and reinforce this through operation of the permit-to-work system.</td>
<td>Hold daily or per-shift meetings between the yard and the vessel.</td>
</tr>
<tr>
<td></td>
<td>Hold daily or per-shift meetings between the yard and the vessel.</td>
<td>Ensure effective reporting of all violations, incidents and near-misses and the updating of the safety framework to reflect learnings from incidents.</td>
</tr>
<tr>
<td></td>
<td>Ensure effective reporting of all violations, incidents and near-misses and the updating of the safety framework to reflect learnings from incidents.</td>
<td>For an LNG tank with active BOG management in place, during dry-docking work the shipowner and shipyard should conduct joint risk assessment to understand daily control and co-ordination measures – reporting of tank pressure and boil-off management by GCU, boiler or auxiliary engine system.</td>
</tr>
<tr>
<td></td>
<td>For an LNG tank with active BOG management in place, during dry-docking work the shipowner and shipyard should conduct joint risk assessment to understand daily control and co-ordination measures – reporting of tank pressure and boil-off management by GCU, boiler or auxiliary engine system.</td>
<td>If proceeding would be unsafe, stop work and raise the alarm.</td>
</tr>
</tbody>
</table>
### Table 6.2: Roles and responsibilities (continued)

<table>
<thead>
<tr>
<th>Role</th>
<th>Shipyard</th>
<th>Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervisors (employed and subcontracted)</td>
<td>Brief employees and visitors on the safety framework.</td>
<td>Ensure additional briefings to cover: the use of specialised procedures and equipment; hazards; and work in particular spaces. Solicit feedback to ensure that briefings have been understood. Monitor work to ensure that the safety framework is adhered to and, if necessary, stop work. Effectively report all safety framework violations, incidents and near-misses to management in a timely manner.</td>
</tr>
<tr>
<td>Workers (employed and subcontracted)</td>
<td>Attend briefings and ask for clarification if instructions and rules are unclear or appear inappropriate. Observe safety notices and exclusion areas. Follow briefings and working practices – for example, the wearing of PPE and the use of correct tools. Stop work if proceeding would be unsafe and raise the alarm with the supervisor. Report safety framework violations, incidents and near-misses to the supervisor.</td>
<td></td>
</tr>
<tr>
<td>Visitors</td>
<td>Attend a briefing on the safety framework and ask for clarification if information is unclear. Observe safety notices and exclusion areas. Follow briefings and working practices – such as the wearing of PPE and the use of correct equipment.</td>
<td></td>
</tr>
</tbody>
</table>

To enable a shipyard to perform, a vessel’s owner needs to:

- provide an HSE bridging document defining arrangements for all interfaces
- provide trained and competent engineers and superintendents in sufficient number to monitor shipyard work effectively
- provide briefings, at least on safety, to all yard personnel
- if needed, provide specialist safety briefings on specific equipment
- provide drawings, layouts/models and walk-throughs of gas hazardous areas and safety-sensitive areas
• have a permit-to-work system in place and effective worker communication systems
• assess the quality of its own subcontractors and, if necessary, impose “LNG-ready” behaviours and working practices
• impose or support yard with access controls for hazardous areas and safety-sensitive areas

6.7.1. Project Co-ordination
In conjunction with the work control processes described in Section 5.3, there should be significant communication and co-ordination between the yard and the owner, which, as a minimum, should involve a daily meeting of the vessel’s supervisory staff and the shipyard staff. This meeting should look forwards to prepare the coming day of work and look backwards to close out work completed or reassess it if it is ongoing. Alternatively two meetings might be held one to open the day’s work and the other to close it.

The yard project manager and the vessel superintendent (and/or master) should attend. If more than one shift is operating within the yard, this meeting should be held for each shift to ensure that any issues, actions and unresolved risks are clearly identified and transferred to the next working team. Significant subcontractors working for either the shipyard or the vessel should also have representatives present.

The agenda for these meetings should, as a minimum, address the following issues and any actions that are required:

• the status of the gas management plan (tank pressure and level)
• review any incidents and near-misses since the last meeting and consider whether any changes need to be made to working plans
• review and record any good practices since the last meeting
• work activities to be undertaken:
  • organise any specific safety briefings
  • define how work will be supervised by BOTH yard and vessel staff
define any time limitations on the work
issue any revised drawings (for example, altered hazardous zones) to support the work activities
understand progress on longer-term projects which are handed over from shift to shift
remove or resolve any clashes between work items and identify work tasks that are incompatible with each other

• work activities that require a permit-to-work, including:
  activities that may increase the probability of a release of LNG or gas – for example, maintenance on valve actuators and sensors
  any reduction in automated safety monitoring – black-outs, sensor calibration and so on
  work to be conducted in hazardous zones or safety-sensitive areas
  activities that could introduce an ignition source into or near to a hazardous area
  maintenance of isolations and mitigations for renewal of permits for overrunning and longer-term work

• work activities that may conflict with one another (SIMOPs), requiring additional supervision or risk assessment:
  potential conflicts on the vessel
  potential conflicts around shipyard activities alongside or vessels moored adjacent to the gas-fuelled vessel undergoing maintenance

• review any necessary changes to contingency and emergency plans from specific operations on or around the vessel or from anticipated changes in the weather (for example, high winds)

6.7.2. SIMOPs
SGMF has provided guidance on SIMOPs during bunkering in “FP08-01 Simultaneous Operations (SIMOPs) during LNG bunkering”. The guidance given here is a re-interpretation of that document for maintenance.
SIMOPs can create additional risks by introducing additional hazards, increasing the likelihood of an LNG/gas leak, and/or escalating an incident, should one occur, by increasing the severity of consequences. With respect to SIMOPs, risk management and mitigation is all about placing barriers between threats and the consequences.

**Threats** A threat is an event that has the potential to cause a hazard, such as a release of LNG. In this case it is only a threat when LNG is present.

**Consequences** Consequences are the potential outcomes of a hazard. Again, actions can be included to prevent or mitigate these consequences.

**Barrier** Barriers are actions, policies, physical design features and/or active and passive safety systems which stop a threat leading to a hazard or prevent/mitigate the consequences.

SIMOPs are defined as **LNG or gas operation plus one or more other activity and/or operation conducted at the same time where their interaction may adversely impact safety, ship integrity and/or the environment.**

In a maintenance/dry-docking context the LNG operation could mean:

- transfer of LNG on or off the vessel or between two tanks on the vessel is essentially bunkering (which is extensively covered in SGMF’s FP08-01 “Simultaneous Operations (SIMOPs) during LNG bunkering”
- cooling down and gassing up (essentially bunkering – see FP08-01)
- storing and controlling the pressure of LNG onboard a gassed-up vessel
- pressurising and vaporising LNG for use by gas-consuming equipment (engine, boiler, GCU and so on)
- a vapour release as a result of a failure of the gas-management plan
Four types of activity are defined:

- regular SIMOPs
- non-standard but planned
- non-standard and unplanned
- external activities

In a dry-dock/shipyard context, the activities should all fall under the non-standard but planned category. The whole tendering and work processes are the result of intensive planning of irregular maintenance and repair activities by both the owner and the shipyard. Examples of these operations include:

- the use of non-intrinsically-safe electric or sparking machinery or tools
- the testing of high-power radio and radar systems
- maintenance and testing of power generation systems (black-out concerns)
- maintenance and testing of control systems (full functionality may not be available/spurious alarms distract people from other, potentially more important, activities)
- the testing of cargo equipment (cranes, conveyors, pumps and so on)
- control system software upgrades (in local or centralised systems)
- hold cleaning
- hull cleaning and painting
- maintenance and testing of non-intrinsically-safe electrical equipment
- hot work, welding, grinding or paint removal (using blow torch), or the use of sparking tools
- lifting operations

External activities can be considered to be the work under way on neighbouring vessels or in dockyard facilities – such as welding, vehicle movements and so on – which might impact the gas-fuelled vessel.
undergoing maintenance. The interactions between different vessels and yard areas should be planned activities co-ordinated across the shipyard.

All these SIMOPs need to be risk assessed and approved (or prohibited/delayed, as necessary).

The key roles of supervisors and those monitoring the maintenance both owner and shipyard are to:

- stop any SIMOP which significantly increases risks or makes the LNG operation unsafe
- ensure that only authorised personnel (trained, required for their role and properly equipped) are within the appropriate hazardous zone and safety-sensitive areas
- ensure that any risk mitigations, including SIMOP restrictions, are in place and remain in place and uncompromised
- communicate clearly, effectively and continuously with all parties involved

During an emergency/unplanned dry-docking there may be hazardous cargo or passengers to be managed.
7. Special Working Practices for LNG

The cryogenic nature of LNG and the volatility of IGF fuels require additional specialised procedures and working practices. These include:

**Gas volatility**
- isolation of equipment and piping segments
- removal of flammable material from equipment/piping segments by purging and inerting
- measurement and monitoring of flammable gases
- measurement and monitoring of breathable atmospheres
- maintaining the integrity of intrinsically-safe electrical equipment using appropriate sealing arrangements
- minimisation of flanges and other non-welded joints

**Cold working**
- importance of cleanliness in cryogenic systems
- avoidance of moisture ingress into cryogenic equipment/piping
- seals and lubrication at cryogenic temperatures
- special precautions required when storing and working with aluminium and stainless steels
- the need to accommodate expansion and contraction during warming up and cooling down
- working with insulation materials for cold protection
- injuries resulting from exposure to cold

**Other procedures**
- lifting over deck-mounted LNG tanks and piping
These practices are described in outline in the following subsections.

### 7.1. Isolation of Equipment and Piping Segments

Valves are typically used to isolate one part of a gas or liquid system from another. If a valve is closed, the pipework downstream of the valve can be emptied of gas and worked on safely while gas remains in the piping upstream of the valve. Isolations when completed need to be proved effective. If the isolation is a single valve then if this valve leaks the isolation fails. Even if leak rates are very low the volume leaking over time may be significant. The higher the pressure differential across the valve, the higher the probability of a leak.

Two valves in series provide much better protection than a single valve as both will need to leak for the isolation to fail. A double-block-and-bleed system involves two valves to block any flow, with a bleed valve between them which allows any gas passing the first block valve to be vented to atmosphere via the vent system. Valves are only one form of isolation. If there are particular concerns, other options are available, such as:

- blinds or spades – effectively a blank flange that can be inserted into the pipe to block the whole cross section
- removable sections – a piece of pipe that can be totally removed ensuring that there is no path along which fluid can flow, often used where a tank or pressure vessel (confined space) needs to be entered

All isolations may leak if they are not properly implemented. Human error is a major factor in such failures. For example, a worker may fail to identify the correct valve and close another valve instead, or may not manage to get a blind into the correct position so that it does not isolate the whole pipe.

The UK Health and Safety Executive (the safety regulator in the UK for onshore and offshore oil and gas facilities as well as shipyards) provides a detailed review of isolation procedures in the document “HSG 253, The safe isolation of plant and equipment” (http://www.hse.gov.uk/pUbnsp/ priced/hsg253.pdf).
The HSE defines three criteria where additional precautions should be taken to ensure that isolation is guaranteed. Two of these are appropriate to LNG and gas.

- vessel entry – personnel entry into a LNG tank when connections to other tanks and filling systems are present and may be compromised
- isolation of toxic fluids – not appropriate but nitrogen as an asphyxiant should be treated similarly
- where overpressure may occur
  - firstly through vaporisation of trapped LNG where no thermal relief valve is provided and
  - secondly by back flow from a high pressure gas system such as an M-type, electronically controlled, gas injection (MEGI) engine to a lower pressure system such as the LNG tank

Normally, additional precautions are taken with valves in cryogenic LNG service as any loss of LNG will be followed by rapid boiling, leading to hazards far greater in extent than the amount of liquid spilled. Additionally, if any moisture is left in the LNG piping system, this will become ice and may prevent the valve from sealing properly and therefore effectively isolating the system it was designed to protect.

Isolation philosophy should be defined and implemented by the owner and may therefore vary from vessel to vessel. Typical isolation concepts are shown in Table 7.1.

The IGF Code requires a higher level of isolation reliability in some applications to that suggested in Table 7.1. In most instances this results in the use of double-block and bleed system for isolation rather than single- or double-block valves. As Table 7.1 shows, other isolation strategies of equal reliability are available – for example, positive isolations.

It is good practice to isolate LNG tanks during maintenance, as close as possible to the tanks, unless a specific LNG/gas-system commissioning activity is planned. This prevents the largest reservoir of hazardous material from flowing to other parts of the vessel. Again, purging all
downstream pipework to remove all flammable gases is good practice as it removes another hazard from consideration during maintenance. An isolation should:

- be locked in the appropriate position (open or closed) with an interlock (for example, car seals) or more normally through a chain and padlock, with the key kept securely away from the immediate job site
- have the actuating mechanism (electrical cable or instrument air connection) removed while in its fail-safe position (open or closed, as appropriate); this isolation is less secure as a worker could reconnect the actuating mechanism

Other isolation methods, such as tagging valves, are less effective as it may be possible for workers to ignore or circumvent them.

Different types of valves are used for different duties. For isolation purposes:

- ball and plug valves are the best choice as they are normally open or shut, so their sealing ability is unlikely to be degraded and therefore very high. These valves are easy to operate, so should be disabled when in position.
- globe, butterfly and gate valves are normally adequate but valve surfaces are exposed to fluid flow which means that their sealing ability is not certain, particularly in the case of gate and globe valves used for pressure or flow control.
- needle valves are used for control and may not provide a positive seal, so they are not effective as isolation valves.
Table 7.1: Isolation philosophies (based on HSG 253)

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Service</th>
<th>Isolation concept</th>
<th>Example drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG</td>
<td>Piping with diameter &lt; 8 inch and at a low pressure of less than 18 bar (Class 150)</td>
<td>Single-block</td>
<td><img src="image" alt="Drawing" /> Equipment and/or piping under maintenance or inspection</td>
</tr>
<tr>
<td>LNG</td>
<td>Piping 8 inch diameter or larger or Pressures higher than 18 bar (Class 300)</td>
<td>Double-block and bleed</td>
<td><img src="image" alt="Drawing" /> Equipment and/or piping under maintenance or inspection</td>
</tr>
<tr>
<td>Fuel gas, BOG or LNG</td>
<td>Entry into an LNG tank or other confined space of a process vessel containing gas and/or LNG – for example, an external LNG pump can</td>
<td>Positive isolation</td>
<td><img src="image" alt="Drawing" /> Equipment and/or vessel/space being entered</td>
</tr>
<tr>
<td>Fluid</td>
<td>Service</td>
<td>Isolation concept</td>
<td>Example drawing</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------------------------------</td>
<td>-----------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fuel gas and BOG</td>
<td>All pipe sizes</td>
<td>Single-block</td>
<td><img src="image" alt="Fuel gas and/or BOG" /> Equipment and/or piping under maintenance or inspection</td>
</tr>
<tr>
<td></td>
<td>Low-pressure gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Typically, pressures &lt; 100 bar (Class 600)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>All pipe sizes</td>
<td>Double-block</td>
<td><img src="image" alt="Fuel gas and/or BOG" /> Equipment and/or piping under maintenance or inspection</td>
</tr>
<tr>
<td></td>
<td>High-pressure gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Typically, pressures &gt; 150 bar (Class 900)</td>
<td>Double-block and bleed</td>
<td><img src="image" alt="Fuel gas and/or BOG" /> Equipment and/or piping under maintenance or inspection</td>
</tr>
<tr>
<td></td>
<td>All pipe sizes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>All pipe sizes</td>
<td>Double-block and bleed</td>
<td><img src="image" alt="Nitrogen" /> Equipment and/or piping under maintenance or inspection</td>
</tr>
<tr>
<td></td>
<td>All pressures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Valves and gauges shown in grey are optional; they are there to prove the sealing of the second block valve.
Key isolations

• the IGF Code requires that a double-block and bleed valving system is provided on the fuel-supply piping to all gas-consuming equipment, such as engines and generators (IGF 9.4.4), and on the inert gas-supply pipework to the gas-fuel system (IGF 6.13.2), to prevent flammable gas entering the inert gas system and flowing through it to other parts of the vessel.

• pressure and thermal-relief valves that open onto common vent headers will need to have isolation valves between them and the header to allow their removal and maintenance. If the relief valve connects to a hazardous space – for example, a PRV on the LNG tank – an isolation valve onto the protected system will also be required.

• nitrogen has a higher level of isolation because of its asphyxiant properties and relatively high pressure, particularly if bottle packs are used.

7.2. Removal of Flammable Material From Equipment/Piping Segments by Purging and Inerting

LNG vapour and natural gas can be removed from equipment and piping systems by purging – replacing the flammable gas with an inert (non-flammable) gas. Nitrogen is the preferred inert gas.

The aim of purging is to change the atmosphere in a system without passing through the flammable range of the fuel. This is shown schematically in Figure 7.1. The green line is correct, while the orange one – which goes directly from breathable to inert – is not because it passes through the flammable zone.
Purging will temporarily change a hazardous area (Zone 0, 1 and 2) to a non-hazardous one.

There are two methods of purging:

- through flow of inert gas
- pressurisation and depressurisation using an inert gas

The method used depends on: the size and shape of the system being purged, the time of contact, the speed of the purging process, and the properties of the gases involved.

Flowing an inert gas through a system for a period of time and measuring the composition of the gas leaving the system is the easiest option. The aim of the through flow of an inert gas is to create a piston effect that drives the flammable gas out of the system. This only works well if the gases do not mix effectively, which requires a small contact area like a pipe, and a process fast enough to stop diffusion of the gases but slow enough not to cause mixing when the two gases meet.

Through flow does not always guarantee that the system is free of flammable gas if the surface area is large – for example, it includes tank
or pressure vessels – or if gas can become trapped in pockets and dead ends. After completion of purging, the flammable gas will diffuse back into the supposedly gas-free system from the dead ends and pockets. If this method is used, the location of the purge and drain points and the duration of purging need to be carefully considered. Gas leaving the system must be checked to show that it is methane-free.

For large-volume systems, pressurising a system with an inert gas is a much more rigorous purging method. Pressurisation forces the mixing of the flammable gas with the inert gas. The process takes longer to ensure that mixing is complete and uses more inert gas. The dilution effect is best explained with an example:

\[
\text{Flammable gas in system at 1 bar pressure at start } = 10 \text{ m}^3 \\
\text{Inert gas introduced to pressurise to 6 bar } = 50 \text{ m}^3 \\
\text{Flammable gas in the first depressurisation } = \frac{10}{(50 + 10)} = 16.7\% \\
\text{Composition is above the upper flammable limit of methane (15%) and is therefore safe} \\
\text{Flammable gas in the system at start of second pressurisation } = 16.7\% \times 10 \text{ m}^3 = 1.67 \text{ m}^3 \\
\text{Inert gas in the system at start of second pressurisation } = 10 \text{ m}^3 - 1.67 \text{ m}^3 = 8.33 \text{ m}^3 \\
\text{Inert gas introduced to pressurise to 6 bar } = 50 \text{ m}^3 \\
\text{Flammable gas in the second depressurisation } = \frac{1.67}{(50 + 10)} = 2.8\% \\
\text{Composition is below the lower flammable limit of methane (5%) and is therefore safe – meaning the system has been purged successfully}
\]

Pressurising and depressurising takes longer but purging is guaranteed, so long as enough time is allowed for complete mixing. Equipment may have a pressurisation rate limit but will almost certainly have a depressurisation rate limit. As gas expands, its temperature reduces (the Joule-Thomson effect) and may exceed structural or stress limits if depressurisation is too fast.
The successful completion of purging needs to be confirmed by measurement. When a gas sampling point is selected, the properties of the various fuel and inerting gases need to be considered, particularly density. If the system is still cold, nitrogen will be less dense than methane so sampling the vapour pipe from the tank may show that the atmosphere is inert while sampling a liquid line might indicate the opposite. If the system is warm, methane will be lighter than air and might be present in the vapour line and not in the liquid line.

The location of measurements will depend on the work being undertaken. The following sample points are suggested:

- LNG tank outlet pipework (if the tank is to be entered)
- pumps and vaporisation circuits
- pipe supplies to all main gas-consuming equipment and at each gas valve unit (working on engines and boilers)

7.3. The Need to Accommodate Expansion and Contraction During Warming Up and Cooling Down

The cold temperature of LNG causes pipework to contract. This can lead to over-stressing, distortion or leakage if pipe support systems are not correctly located to allow the contraction to occur. Normal pipes remain warm and do not suffer these issues and so have much less stringent support requirements.

On large pipes, the differences in temperature between the top and bottom may be sufficient for the pipe to bend: the bottom, being coldest, contracts more than the top, resulting in a pipe that looks like a banana. In most LNG-as-fuel situations it is the contraction (or expansion) of the whole pipe that is important. The pipe needs to be able to move on its supports or it will become stressed, which could result in leaks from flanges or even the cracking of welds. To allow movement, cryogenic pipework needs to incorporate devices which can change shape to reduce stresses – either bellows or expansion loops. Bellows are
corrugated sections of pipe that can readily expand and contract. Expansion loops have four right angle bends which can safely change angle to accommodate movement.

**LNG Incident**

A design error was identified on a floating LNG import terminal (FSRU) during the testing of an Emergency Shut-Down (ESD) circuit for the high-pressure gas export arm. A missing restriction orifice caused a high flow into the pipeline, which took a tortuous route including 90° bends over a distance of about 150 metres to the vent stack. The high flow caused the piping to break free from its supports and straighten.

Speed of contraction is important so that stresses are distributed and do not build up. Figure 7.2 shows an LNG road tanker loading bay where LNG is loaded for use as fuel. The pipework was cooled down too quickly, resulting in the wooden pipe support being pushed out and falling to the ground. The pipe is no longer properly supported.

*Figure 7.2: LNG road tanker loading line cooled too quickly resulting in the pipe support being ejected and the pipe being operated without the correct support arrangement. (© Penguin Energy Consultants Ltd)*
7.4. **Minimisation of Flanges and Other Non-Welded Joints**

Welded joints, if properly tested on completion, provide the highest degree of certainty of leak-tightness. The weld is of similar strength as the pipe and therefore unlikely to leak. Other connecting systems – such as bolted flanges, screw threads and NPT threads – rely on gaskets and tortuous gas paths to stop leakage and therefore provide less certainty of leak-tightness.

In general, the use of flanged connections is kept to a minimum. However, they are essential in LNG systems to allow maintenance of key components, such as valves and instrumentation, and larger equipment, such as pumps and compressors, which need to be removable from the piping and ship’s structures. Contraction and expansion place strains on flanges, just as they do on other piping system components. However, if the flanged pipe contracts less than the bolts holding the flanged connection together, the flange may open up and leak. Flange bolts therefore need to be:

- of the correct metallurgy/specification so that they contract to the correct size when cold
- tightened to the correct torque level when installed
- re-tightened to the correct torque level when cold

Gaskets similarly need to be of the correct material, clean, and installed as specified. For flanged joints this is a “once for a long period” process. When quick connectors are used – for example, on hose connection systems – this process has to happen frequently. Gasket inspection and cleaning will be required every time, and gasket replacement may be required after several uses.

Screwed couplings (also known as compression fittings) are only allowed under the IGF Code in accessory and instrumentation lines and then only up to a diameter of 25 mm.
7.5. The Importance of Cleanliness in Cryogenic Systems

The need to warm up and cool down LNG systems to allow safe working makes the removal of debris caused by poor worker cleanliness practices a long-winded process. It also extends the duration of downtime and heightens loss of economic performance.

For example, if a welding rod is left in a system, it may move during purging or gassing-up and lodge in the seat of a valve. In this location it may stop the valve opening or closing. This limitation may only be discovered when the system is gassed-up and cold. To remove the welding rod the system needs to be isolated, purged (a couple of hours), warmed up (6 -8 hours), entered to remove the welding rod, purged (another couple of hours) and cooled down (another 6 -8 hours). So this simple failure results in about a day off-hire as well as potentially emissions to atmosphere from the venting/purging process.

Importance of Supporting Systems: Glycol System
Glycol is used to protect important areas of the vessel and to vaporise LNG because its freezing point (about -40°C) is much lower than that of water (0°C). However, as in a car anti-freeze system, the exact freezing properties depend on the relative composition of the protective mixture: too much water and the mixture will freeze early and, because freezing materials expand, this could damage the system. Any dirt that gets into the system through maintenance or poor filling provides a site for freezing to start from. Glycol is not to cryogenic specification so more foreign material is likely.

During commissioning of one glycol system after maintenance, dirt plus an excessively watery glycol solution led to freezing in the glycol-warmed LNG fuel vaporiser system. This caused pipes within the heat exchanger to fracture, necessitating replacement.

7.6. Measurement and Monitoring of Flammable Gases

There are many ways to detect flammable gases. Because no single technology performs all the necessary detection requirements in all
circumstances, a variety of sensor types are typically used, depending on installation location, and local weather and environmental conditions. Gas detectors will be connected to the fire-and-gas-management control system.

Sensors are designed for “point” and “area” monitoring. In “point” mode, the detector is limited to a small area – for example, a flange, valve and/or short length of pipe. In “area” mode, a complete space may be monitored – for example, the whole engine room or tank location. Area type sensors require consideration of a wider range of possible interference from locational factors – for example, smoke detectors may also be triggered by airborne dust particles that may be generated during maintenance work.

Flammable gas detectors use three basic principles:

- catalysts that cause any flammable gas to react with air, creating heat that can be measured by an electronic circuit (these can only be used if oxygen is present)
- infrared radiation, which is absorbed at different wavelengths by different gases, with hydrocarbon (flammable) gases absorbing preferentially at around 3.4 μm
- acoustic leak detectors that sense the high-frequency ultrasound transmitted as a high-pressure leak depressurises as it passes through a leak path to the atmosphere

Flammable gas-detection sensors need to be sited where gas may be present. This may be both high and low. Vaporised LNG is heavier than air and slumps downward until it warms to about -110°C; above this temperature it is lighter than air and therefore rises.
Example: Norway 2014
In May 2014, during the bunkering of a RoPax vessel, incorrect support of a hose while SIMOPs were being performed on the ferry resulted in the over-stressing of the emergency disconnect coupler, causing LNG to leak. The gas-detection system onboard the vessel did not register this leak; it was eventually spotted by an operator about 40 seconds after it had begun. The gas detector in the ferry’s bunkering station failed to detect the leak because it had been installed above the manifold while the mixture of gas and LNG was very cold and so was moving downwards.

It is not uncommon for flammable gas-detector sensors to generate errors, or drift from calibration, so they need to be tested regularly and, if necessary, recalibrated. This can be carried out in-situ, at least annually, by qualified members of the ship’s crew or specialist contractors. Testing involves releasing small amounts of test gases (known amounts of methane in air and/or nitrogen) to trigger an alarm and, if necessary, changing the sensitivity of the alarm point. Easier access to detectors means that calibration is likely during dry-docking. While being calibrated, the detector will not be able to detect gas in the immediate vicinity.

Catalytic Gas Detectors
Catalytic gas detectors, also known as Pellistor detectors, are one type of “point” detector. They typically use a metal catalyst embedded in a ceramic base that also contains an electrically heated platinum wire coil. Flammable gas oxidises across the catalyst, producing heat, which changes the resistance in the platinum coil, thereby producing a detectable signal. The degree of heating is proportional to the amount of flammable gas present. These detectors have three known issues, which can be exacerbated by maintenance processes:

- the catalyst can be poisoned by silicon-based greases
- the ceramic disc can be blocked by particulates, such as oils, fine dust, salt, grit, corrosion and water
- they only work when there is oxygen present in the atmosphere being monitored
**Portable Flammable Gas Detectors**  
Portable flammable gas detectors operate in the same way as the fixed sensors but are not connected to the fire-and-gas-management system; instead they have their own local alarm to alert the operator. Portable gas detectors should be calibrated regularly, preferably before each use (each shift) by an approved person – for example, the certified chemist – using a test gas. Battery function and charge should also be confirmed before the device is issued.

**Other Leak-Detection Devices**  
Flammable gas detectors will detect all flammable gas leaks that come into range of the sensor. Other technologies – such as thermocouples/temperature switches and optical fibres – can detect leaks that result in large temperature changes, such as LNG spills, if sited correctly.

### 7.7. Measurement and Monitoring of Breathable Atmospheres

Gas-fuelled vessels may contain spaces which, because of leaks, have atmospheres where oxygen has been displaced by flammable gas. More importantly, gas-fuelled vessels use considerable volumes of nitrogen to avoid flammable atmospheres and for the purging of piping and equipment systems, particularly before and after maintenance. Nitrogen can also displace oxygen from the air, making the atmosphere in a space non-breathable.

When a person enters a potentially non-breathable space, the atmosphere should be checked using a portable oxygen meter. Checking should continue periodically, say every 30 seconds, while someone is in the space.

Oxygen meters provide alarms at 19% and 17% oxygen. Humans start to breathe faster at about 19% and body performance deteriorates at lower levels, with drowsiness, nausea and abnormal behaviour starting at about 17%. Unconsciousness occurs rapidly at oxygen levels of 10-13%. Death occurs at levels below 6%.
Oxygen sensors are used to measure gaseous or dissolved oxygen. There are many different techniques for measuring gaseous oxygen. Three of the more widely used sensors are:

- galvanic cell sensors
- polarographic sensors
- optical sensors

Galvanic cell and polarographic sensors operate similarly, by the electrochemical reaction of oxygen with an electrolyte to produce an electrical current. The electrochemical reaction consumes a small amount of oxygen. Unlike polarographic oxygen sensors, galvanic cell sensors are self-powered and so do not require input power for operation. One common galvanic technique uses a potassium chloride solution which absorbs oxygen and provides a signal proportional to the amount of oxygen present.

Optical oxygen sensors use optical fibres and a fluorescence method to measure oxygen via spectrometry.

Oxygen sensors can be calibrated in normal air.

7.8. Maintaining the Integrity of Intrinsically-Safe Electrical (ATEX) Equipment Using Appropriate Sealing Arrangements

The potential presence of gas, often through significant areas of a vessel, means that additional precautions must be taken to stop sparks from electrical equipment igniting any leaking gas. There are a variety of methods of stopping electrical system sparks causing ignition (see Appendix C), including:

- reducing spark energies below ignition levels
- stopping flammable gases from entering electrical equipment
- restricting any explosion within the electrical equipment
Whichever route is taken, more care needs to be taken in the re-assembly of electrical equipment to ensure that the protective method – for example, a seal – remains effective. The following components of electrical equipment should be checked:

- the enclosure should be undamaged and not modified from the original without authorisation
- bolts/screws holding the enclosure together should be tight, undamaged, and of the correct type and material
- screws and clips holding electrical components in place should be tight, undamaged, correctly connected and appropriately insulated
- cable glands should be tight and in good condition
- any sealing gasket should be in good condition
- equipment earthing/bonding arrangements should be in order
- cables should be in good condition

Megger testing of power circuits may be required under controlled circumstances because breakdown of insulation may cause arcing.

Intrinsically-safe electrical equipment appears on most ships but on gas-fuelled vessels the extent and number of safe electrical systems is significantly greater.

IEC 60079-17 provides guidance about inspecting and maintaining electrical equipment in hazardous areas.

### 7.9. Avoiding Moisture Ingress Into Cryogenic Equipment/Piping

Moisture from rain or even ambient humidity, if left inside equipment or pipework, will, when the system is cooled down to cryogenic temperatures, freeze and become ice. Cryogenic valves need to be kept drier and cleaner than standard valves or ice will build up under the seat, either leading to damage to the valve or failure to close and isolate flow when required.
Cryogenic equipment (such as valves) removed from the vessel for maintenance must be appropriately protected before being re-inserted into the fuel gas system.

Figure 7.3 Ice found in a pipe in a LNG terminal (© Tuxan Consulting Ltd)

On a vessel, air is normally supplied at a dew point of -40°C to exclude moisture. However, it may still contain enough moisture to cause icing at LNG temperatures. LNG systems need “dry air” at a dew point of -70°C or below to prevent icing. If the air is not sufficiently dry – for example, (instrument) air at -40°C – nitrogen may need to be used for drying.

Pressure-testing of systems is normally done with high-pressure water (hydro-testing). In cryogenic systems pneumatic testing may be required as it may not be possible to remove all the water/moisture from a hydro-test. Gases, like air or nitrogen, are compressible, which means that a pneumatic test contains a large amount of energy should a problem occur. Water is not compressible and so is much safer to work with. To reduce risks, pneumatic testing may need to be performed overnight when most workers are absent.
Example: Pneumatic Testing Failure

In March 2009, one worker was killed and 15 injured when pneumatic testing at a Chinese LNG terminal in Shanghai went wrong. The gas export pipeline exiting the terminal was being pressure-tested when a flange failed at 123 bar (pressure was rising to the test pressure of 150 bar). The death and injury were the result of flying debris (metal fragments, concrete and rock) from the explosion and occurred between 350 and 500 metres away from the flange failure.

Humidity in the air may also affect operations. In hot and humid areas, both geographically (such as Singapore or the US Gulf of Mexico) and spatially within the ship, large amounts of water vapour can build up and become incorporated into the vessel’s equipment and systems. Cryogenic insulation is one such system. If the insulation is put on during periods of high humidity, some moisture will get trapped between the pipe and the insulation. As this cools, it will drop out as liquid and then freeze into ice. This can damage components of the insulation, significantly reducing its effectiveness. Installation of cryogenic insulation may be possible only at night or in the morning when humidity levels are lower.

Tolerances on rotating equipment, if set at high temperatures, may not be effective when it cools down. So tolerances need to be set at the manufacturer’s required temperature in controlled conditions.

7.10. Seals and Lubrication at Cryogenic Temperatures

Lubricants and greases will either solidify or become increasingly viscous as temperature falls. So special LNG lubricants are required for cryogenic service. Lubricants used on other fuel types will not provide any benefit in cryogenic service, leading to equipment damage and/or failure.

The temperature effect is also evident in many sealing compounds. Elastomers and other seals that operate at ambient temperatures may become brittle and ineffective in cryogenic conditions. Specific elastomers or metal gaskets are therefore often required.
7.11. Special Precautions Required When Storing and Working with Aluminium and Stainless Steels

Carbon steels become brittle as temperatures reduce and are therefore inappropriate for LNG service. To maintain their ductility at cryogenic temperatures, steels must contain higher amounts of alloy material so stainless steels are often selected. Stainless steel corrodes via a galvanic process when two dissimilar materials – for example, a stainless steel and a normal steel – touch in the presence of water. Stainless steel must therefore be kept separate from other steels and must be protected from water, particularly salt spray. In humid areas, salt becomes hygroscopic – it absorbs water – and so will cause stainless steel to corrode.

Aluminium is an alternative to stainless steel but also suffers from galvanic corrosion so again needs to be stored separately. The corrosion resistance of aluminium derives from a thin passive oxide coating that forms on its surface when it is exposed to the atmosphere. Unlike the oxide coating on conventional steels, the aluminium oxide coating is continuous, resisting further oxidation. The heavy grey oxide layer must be removed prior to welding, either by hand mechanically using a stainless steel wire brush, or even using a sanding or grinding disk if the material has been poorly stored outside. Water increases corrosion rates in aluminium so stored material should be inside or covered.

Aluminium must be cleaned before it is welded. Firstly, all oils, lubricants, machining coolants and other hydrocarbons used in manufacturing must be removed with a degreaser as they can release hydrogen gas during arc welding which causes welds to be porous.

Weld materials are very specific to individual grades of stainless steel and aluminium. Each has features that require appropriate identification, storage and handling.

Cold systems, such as LNG storage and piping, in or passing through warmer spaces will undergo heat transfer by conduction and convection, where they are warmed as the surrounding space cools, the capability of surrounding steels to maintain their strength and ductility at these lower
temperatures needs to be assured, localised heating may be required. This also affects the use of replacement materials should the original construction need repair or alteration.

7.12. Working With Cryogenic Insulation

Cryogenic insulation takes two forms: firstly, a vacuum that transmits heat very poorly can be created by enclosing a tank or a pipe with another tank or pipe; and, secondly, layers or shells of solid foam material that again transmit heat poorly.

Vacuum insulation is the most effective option but also the most costly. This form of insulation works only if the vacuum is maintained. If it is partially or totally lost, the insulation effect is also lost. The vacuum is sealed in by pipe stubs ending with valves and blanks. Extra care is required when working near these terminations. Sealing of the inner and outer pipes to each other is difficult because one is cold and the other warm. It is accomplished through short corrugated pipe sections. These piping components are much weaker than the surrounding pipes and need to be treated carefully. Fortunately, they are normally sited close to the vacuum valves.

Foam and shell insulation is much more common. A variety of foams may be used, such as PVC and polyurethanes. Volcanic dusts (such as perlite) are melted into specific shapes for use on vessels and pipework. The problem with most of these insulation types is that they have edges where one shell buts up against another or the foam is cut to allow it to fit over a pipe. These breaks allow heat to bypass the main insulation and also allow moisture to enter the insulation and freeze. To avoid this, layers are normally overlapped to stop the breaks in the insulation become full thickness. Moisture barriers, such as metallic foils, are included within and on top of the insulation to prevent moisture ingress.

**WARNING:** The polyurethane foams used in insulation can give off highly toxic hydrogen cyanide gas if ignited.
Insulation and moisture barriers can be damaged by impact – for example, if someone stands on them. They may also not be perfectly aligned and fitted, or fitted when too much moisture was in the air. Evidence of damage can often be seen through beads of moisture forming on the surface of the insulation. These “cold spots” may also indicate a small leak somewhere in the underlying system. The number of layers of insulation and moisture barriers may mean that the leak is some distance from where it manifests on the insulation, having tracked a tortuous route to the surface. Thermal imaging cameras will show both cold spots and colder areas across larger areas of insulation.

Cold spots, provided they are not from small leaks, can be corrected by removing the insulation and replacing it in a more effective way. However, the act of removal will create new potential paths for cold LNG to absorb heat from its surroundings.

Figure 7.4: Layered LNG insulation systems © Penguin Energy Consultants Ltd
7.13. Employing OEMs

The specialised nature of many items of equipment within a gas-fuelled vessel’s fuel system – for example, technology, metallurgy and/or cryogenic tolerances needed – may require, or at least benefit from, servicing by the original manufacturer or specialist service companies. Major maintenance providers may also develop their own in-house capability.

Shipyards provide fewer workers to more complex vessels, where specialists or OEMs are required to perform the work. OEM employers, shipyards and owners, need to control the OEM work items and additional workers to the same level of safety performance as their own staff.

7.14. Lifting Over On-Deck LNG Tanks and Piping

The placing of tanks and LNG/gas pipework on deck can lead to damage to equipment from dropped objects. Crane operations should avoid lifting through hazardous areas (typically above deck-mounted tanks and pipework, and around the vent mast and individual vents). If this is unavoidable, a risk assessment should be performed to decide on appropriate mitigations. The following precautions may therefore be required during maintenance:

- operations should be covered by a permit, with a specialist lifting supervisor in charge and in direct communication with the crane operator
- a lifting path plan should be marked up for hazardous zones and safety-sensitive areas to show which quay-side or dock-side crane operations have been authorised and which require a risk assessment to be carried out
- crane drivers should be briefed on each operation
- crane stops may need to be installed to temporarily stop cranes operating in some areas
- scaffolding shelters with protection roofs may need to be erected to avoid lifted items falling directly onto vulnerable pieces of equipment.
7.15. Injuries Resulting From Exposure to Cold

The human body is affected by cold. There are two impacts: firstly, freezing of specific tissues, primarily the skin of the hands; and, secondly, body-wide effects of cold. These are described below. The correct wearing of personal protective equipment (PPE) will protect most individuals from all but the largest of leaks.

7.15.1. Cold/Cryogenic Burns

Human flesh can be damaged if it comes into contact directly with LNG or indirectly through contact with uninsulated pipework. Brief exposures that would not affect skin on the face or hands can damage delicate tissues such as the eyes. Prolonged exposure of the skin or contact with cold surfaces can cause frostbite. Cryogenic burns are similar in many ways to hot burns. Note that it is not just LNG that can cause cold burns – BOG, at least initially, is cold enough to cause burns.

Signs and symptoms include:

- the skin appears waxy yellow
- there is no pain initially, but it becomes intense as frozen tissue thaws

Unprotected skin can stick to metal cooled by cryogenic liquids. The skin can then tear when pulled away. Even non-metallic materials are dangerous to touch at low temperatures. Prolonged breathing of extremely cold air may damage the lungs.

The wearing of whole body coveralls with sleeves rolled down, boots or enclosed shoes, and gloves will prevent most injuries. Safety glasses and/or goggles will protect the eyes. However, if contact is sustained over a period of time or the leak is large, the effectiveness of PPE will be limited.
Example: How to Wear Gloves
An incident in Scandinavia identified how gloves need to be worn differently, depending on the task that is to be performed, if they are to protect an individual effectively from splashes of LNG. If the worker is working with arms above shoulder height, the gloves should be outside the coverall so that any LNG runs over the gloves and over the coverall. If the worker’s hands will be below shoulder height, the gloves need to be inside the coverall – because if the gloves are outside the coverall, the LNG will run down the coverall sleeves and into the gloves, causing extensive cryogenic burns.

7.15.2. Prolonged Exposure to Cold
If the human body is exposed to low temperatures for a significant period, its core temperature will begin to fall – a condition called hypothermia. This will start to impact cognitive abilities and, if not addressed, will lead to unconsciousness and ultimately death. LNG tanks and piping can never be perfectly insulated and the air temperature around these items will be lower than normal ambient conditions. Some spaces will need heating to reduce the impact on steels and structure but this may not be enough to fully mitigate the effects of cold on humans.

The wearing of correct clothing, including gloves, in these areas is essential. Water also makes a big difference as to how quickly the human body loses heat – so people should avoid going into a cold area with wet clothes or from highly humid spaces.

Example: Road Tanker Incident
A LNG road tanker delivering fuel to a factory in the Caribbean could not seal a leak at the hose connection as the connector was damaged and no tool was available to solve the problem. The driver suffered burns trying to stop the leak. The factory was evacuated but people stopped to take photographs. A gas explosion 40 minutes after the leak started killed 8 people.
The onset of hypothermia is slow, so the condition can easily be missed.

1. First-stage hypothermia (Body temperature of 35-37°C)
   • physical and mental tiredness, failure to respond to and understand questions, lack of enthusiasm

2. Second-stage hypothermia (32-35°C)
   • slow thinking, failure to answer questions, tasks performed poorly, speech may be slurred, lack of muscle co-ordination (stumbling, clumsiness), unreasonable behaviour (complaining, swearing, aggressiveness), shivering, problems with vision

3. Third-stage hypothermia (28-32°C)
   • semiconscious or unconscious, pale skin with grey/blue tinges, slow breathing, weak heartbeat, irrational

4. Death (25-28°C)

7.15.3. **Frostbite**

As core temperature falls, the human body tries to maintain it by shutting down blood flow to extremities such as hands and feet. If this process continues for a prolonged period of time, the tissues without blood start to die. As blood keeps these tissues warm, they also cool and exhibit some of the same behaviours and symptoms as cold burns.
8. Gas Freeing and Gassing Up

Gas freeing is the process of removing LNG from a fuel tank and replacing the flammable atmosphere present with an inert gas, normally nitrogen. Gassing up is the reverse process, by which a previously inerted tank is returned to a cold condition suitable for the presence of LNG fuel.

Gas freeing (and gassing up) may be required if:

- a shipyard is unable to get approvals from its licensor/competent authority to work on a gassed-up vessel
- entry into an LNG tank is required for inspection and maintenance of the tank or associated equipment such as fuel pumps
- the duration of the stay in the yard is so long that the vessel's gas-management plan no longer complies with regulatory requirements

Otherwise, the decision to gas free is an owner choice. Figure 8.1 summarises some of the issues that need to be considered when deciding what and whether or not to gas free.
Figure 8.1: Gas-freeing decision tree
8.1. Removing an LNG Tank From Service

Removing a LNG fuel tank from service – from removing the fuel/flammable gas to having a breathable atmosphere – is a five-stage process. Gas-fuelled ships should be designed to fulfil these operational requirements (see IGF Code 6.10.1):

1. any remaining liquid should be removed, either by transfer to another tank on the vessel or to a tank belonging to another service company, say through a road tanker or bunker vessel and/or evaporation.
2. the tank/equipment should be isolated from other tanks/equipment (Section 7.1).
3. any remaining flammable gas should be removed by purging, which also warms the tank (Section 7.2).
4. a breathable atmosphere should then be introduced.
5. unless the tank is the only tank on the vessel, there should be continuous monitoring of the atmosphere to detect flammable gases to continually prove the isolation.

The main stages are described in more detail in the following subsections.

8.1.1. Fuel Removal/Tank Emptying

Offloading or de-bunkering is the process whereby LNG in the ship’s fuel tank is transferred to a receiving facility using a pump or a pressure differential (also known as a pressure decant). The process is conducted by the vessel’s owner and any subcontractors directly employed by the owner. A shipyard has no responsibility for this transfer other than ensuring the health and safety of its employees and protection of its assets. The receiving facility could be one of the following:

- equipment onboard the vessel that consumes LNG, such as the engines or boiler
- another LNG tank on the same vessel
- via the bunkering connections to a road tanker/ISO container
Transfer of LNG to a tank not onboard the vessel may require additional regulatory approvals.

LNG pumps require a certain level of LNG to be present above their impellers to function. LNG is a boiling liquid, so any input of energy will cause some of the LNG to vaporise. The level of LNG provides a static pressure for the LNG at the impeller, increasing the point at which the LNG will boil, allowing the impellers to pump liquid. As the level/pressure reduces, the LNG will begin to boil and the pump will cavitate – meaning the impellers will not be able to pump the liquid. At this level, the remaining LNG must be removed by boiling away.

Offloading by pressure differential will remove all the LNG down to the base of the outlet pipe. Any LNG lower that this will, need to be boiled away.

If the receiving tank is rated at a lower pressure than the tank being emptied, BOG will be considerable and will need to be managed by the receiver.

Warm BOG or warm nitrogen can be injected into the main fill line at the base of the tank to boil away the remaining LNG.

De-bunkering should be treated as a bunkering operation and all the safety precautions, procedures and checklists employed for the latter should be used. These issues are more fully explored in the joint SGMF, IACS, IAPH publication “gas as a marine fuel safety guidelines – bunkering FP07-01, version 2”.

**8.1.2. Tank Warming**

Tank warming starts with the evaporation of the remaining LNG in the tank (see the previous section) and continues until the tank is gas-free (see the next section).

The warming rate must be controlled to limit differential expansion – for example, between the top of the tank and the bottom – which could overstress the tank itself or other components such as piping connected to
the tank. This is done using temperature sensors located in the top, middle and bottom of the tank. All of the equipment and piping involved will also have warming rates and the warming should be limited to the lowest rate.

Warming up a tank can be a slow process. Many tank manufacturers suggest a warming limit of 10°C/h but this should be confirmed with the specific tank manufacturer. The duration depends on the type of tank (thermal mass), its insulation and the amount of hot gas available. Typically, warm gas is produced via the BOG compressors with the warm pressurised gas being re-circulated to the tank. If the BOG compressors are of the oil-lubricated screw type, precautions must be taken to ensure that no oil enters the LNG tank because when the tank is subsequently cooled down this oil will solidify and possibly block the LNG pipework.

8.1.3. Gas Freeing
If both nitrogen and methane (BOG) are at the same temperature, the nitrogen will be heavier and so will sink to the bottom of the tank displacing methane towards the top of the tank and into piping for disposal. As more nitrogen is added, its level in the tank increases, forcing more methane out into the vent system. Eventually the vent system will be discharging only nitrogen. The tank is now “gas free” (non-flammable).

Gas-fuelled ships may be able to perform their own inerting but the size of their nitrogen systems is generally small, meaning that inerting will take a considerable amount of time. The IGF Code (6.10.4) allows for the supply of inert gas for gas freeing to be provided externally – for example, by a bunker vessel or via a shipyard.

The fuel removal and gas-freeing processes lead to emissions of methane and other hydrocarbons. These emissions need to be avoided in shipyard/port areas as they would contravene the shipyard’s licences. Incineration can be used to overcome methane venting but at the cost of additional CO₂ and NOx emissions.

Methane is combustible only between its upper flammable limit (UFL) and lower flammable limit (LFL). In air (20.9% oxygen, 79.1% nitrogen) these limits are 5% and 15%. As the amount of nitrogen increases (and therefore the oxygen declines) the UFL decreases to eventually meet the LFL at 5%,
at an oxygen concentration of about 10%. As the nitrogen content of the gases from the LNG tank changes, maintaining stable combustion will become much harder.

Two items of equipment commonly found onboard vessels can burn the gases from the tank venting:

- GCUs
- boilers

Unless specifically designed, neither piece of equipment can burn all the possible compositions during the gas-freeing (or gassing-up) process. Boilers are, in any case, likely to be too small to perform the combustion required in a reasonable timescale. GCUs are typically designed for 50% methane in nitrogen and so will not be able to deal with methane levels below this. Some industrial flare systems may be able to operate down to 30% methane.

At methane compositions below 50% the gas will need to be vented or combusted in specialised equipment. The methane will need to be heated – to above its auto-ignition temperature of 537°C using hot, oxygen-containing gases. When the auto-ignition temperature is reached, the methane will combust to form CO$_2$ and water vapour. If the ship is a dual-fuel vessel, its alternative oil fuel can be used to fuel the combustion unit (specifically designed boiler or GCU).

Given current pressures to reduce emissions of greenhouse gases, the venting of any sizeable quantity of methane (a greenhouse gas about 30 times more potent than CO$_2$) is unlikely to be acceptable to onshore regulators. If venting is allowed, then methane concentrations in the vent system are likely to be significantly below the LFL of 5%. The IGF Code (Section 15.9) suggests setting gas-detection limits at 40% of LFL, which means methane levels below 2.0%.

Controlled combustion using specialised equipment, called a flare or gas incinerator, within the yard may be required for gas disposal. Additional fuel may need to be burnt to ensure that the vent gases are combustible at all times.
8.2. LNG Fuel Tank Reinstatement

An LNG-fuelled vessel that has had a fuel tank emptied for inspection and/or maintenance does not have to be fully reinstated and gassed up in the yard. This is a decision for the owner. The vessel can leave the yard with:

- the tank warm and oxygenated
- the tank warm and inerted with nitrogen
- the tank cold (at or below -140°C) and inerted with nitrogen
- the tank cold and filled with LNG and BOG

These activities can be performed by a competent crew but the involvement of specialists (or OEM staff) is likely.

If the yard is unable or unwilling to inert/cool down and gas up the vessel, a dual-fuel vessel could proceed to another local area for this service. The tank system should then be checked for leaks, and monitored to assess whether the yard has correctly closed the tank up, in a “mini” gas/sea trial before acceptance by the owner.

Reinstatement consists of four stages and is essentially the reverse of the gas-freeing process. The stages are:

1. the removal of moisture from the system (drying).
2. the removal of oxygen from the system (inerting).
3. cooling down the tank.
4. changing the tank atmosphere from inert to flammable.

The following subsections describe each step in more detail.

8.2.1. Drying

The fuel tank needs to be dry before it is cooled down. Otherwise, water will condense as the temperature falls, eventually forming ice, which may prevent effective operation of valves and instrumentation.

A 100 m³ LNG fuel tank at ambient conditions of 25°C and 80% humidity
contains 0.018 kg of water in every cubic meter; when cooled down, it would produce nearly 25 litres of water.

The moisture needs to be removed from the tank by displacing the wet air with a drier alternative. Dry air onboard a vessel typically has a dew point of -40°C while LNG-specification dry air has a dew point of -70°C. The options are shown in Table 8.1.

As can be seen from the table, to prevent ice formation the dew point of the atmosphere must be reduced to -70°C or below.

There are therefore several drying scenarios, many of which also provide some degree of cooling, as shown in Figure 8.2. The green dotted lines represent the dew point and temperatures which must be exceeded.

<table>
<thead>
<tr>
<th>Dew point</th>
<th>Water</th>
<th>Water condensed</th>
<th>Water remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient air 25°C</td>
<td>312 ppmV</td>
<td>-</td>
<td>25.0 litres</td>
</tr>
<tr>
<td>0°C</td>
<td>60</td>
<td>18.9 litres</td>
<td>6.0</td>
</tr>
<tr>
<td>Ship dry air -40°C</td>
<td>1.27</td>
<td>24.9</td>
<td>0.1</td>
</tr>
<tr>
<td>LNG-specification dry air</td>
<td>-70°C</td>
<td>0.226</td>
<td>25.0</td>
</tr>
<tr>
<td>Ship nitrogen -70°C</td>
<td>0</td>
<td>25.0</td>
<td>0</td>
</tr>
<tr>
<td>Cryogenic nitrogen &lt; -100°C</td>
<td>0</td>
<td>25.0</td>
<td>0</td>
</tr>
<tr>
<td>BOG &lt;-100°C</td>
<td>0</td>
<td>25.0</td>
<td>0</td>
</tr>
</tbody>
</table>
Shipboard systems alone can provide the necessary drying but, unless BOG is available from another LNG tank, are unable to provide the required cooling.

Like purging, drying can be performed by passing dry gas through the tank (making sure that the dry gas mixes with the whole contents of the gas) or by pressurisation and depressurisation.

**Example**

One manufacturer defines the procedure in the operating and maintenance manual as follows:

Using ship’s dry air at -40°C dew point, fill and empty the tank three to five times to ensure drying to 2% oxygen level.

Reduce the tank to a dew point of -78°C using nitrogen at atmospheric pressure.

### 8.2.2. Inerting

All oxygen must be removed from the tank before fuel is introduced to avoid creating a flammable atmosphere. Nitrogen is normally used.
If nitrogen is the gas being used, inerting can be performed simultaneously with drying and/or cooling down.

The aim of inerting is to create an atmosphere in which combustion cannot take place. For methane this means below the Lower Flammable Limit (LFL) of 5% or above the Upper Flammable Limit (UFL) of 15%. Both of these values are in air; as the air is replaced with nitrogen, UFL reduces to meet LFL at about 5%.

Using the 5% LFL does not provide any margin for error. The IGF Code (Section 15.8.7) suggests setting gas-detection limits at 40% of LFL, which requires oxygen in the gas leaving the tank to have a methane level below 2%.

8.2.3. Cooling down

LNG should not be put directly into a tank until the temperature of the tank is below -100°C to -130°C (depending on the manufacturer). If the tank is warmer than this, the temperature difference may overstress the tank. Similarly, liquid nitrogen (LIN or LN2), which is 30°C colder than LNG, cannot be used directly in the early stages of cool down.

Cool down starts using either BOG (or vaporised LNG) from another tank or, given the volumes required, cold gaseous nitrogen (GaN) from vaporised LIN. The cold GaN will normally enter the tank through the vapour return line in the bunkering system.

The cool-down rate, typically 10°C/hour, must be controlled using temperature sensors located in the top, middle and bottom of the tank to limit differential thermal expansion. The size of the bunkering system pipework may limit the cool-down rate. Similarly, if BOG is used, it will be limited by the amount available. The cool-down rate used must be the slowest rate of all equipment present (such as piping, tank and pumps). The cooling rate of an LNG pump may be slower than that of the tank and pipework.

When the tank is cold, it can be checked for leak-tightness and cold spots. This will confirm whether it has been closed up and reinstated correctly after entry. Cold spots may occur if insulation has been removed and not correctly reinstated or there is a leak in the primary containment system.
LNG fuel pumps may need to be cold soaked (in LNG) for some time before use to ensure that all components of the pump have cooled to the same temperature so that when the pump is spun up rotating parts do not impact stationary parts, causing damage or failure.

In some safety regimes (for example, the USA) LIN is considered a hazardous material. Its coldness, even after vaporisation, means that it is heavier than air so it may accumulate in sumps and lower spaces where it could asphyxiate any personnel present or who subsequently enter the area. The use of LIN may therefore need to be considered in the yard’s licence.

8.2.4. Gassing up

If BOG is used instead of nitrogen, gassing up can occur simultaneously with the cooling-down process.

LNG is typically used for cooling once tank temperatures are below -100°C to -130°C. As nitrogen boils at a temperature 30°C less than methane the LNG displaces the more volatile nitrogen into the vent system gassing up the tank. LNG can be supplied via a bunkering arrangement or transferred from another LNG fuel tank on the vessel.
During gassing up, the composition of the gas leaving the tank will change from pure nitrogen to eventually pure fuel vapour. The same restrictions discussed under gas freeing, covering the ability to burn any flammable content of the gas, apply. The gas exiting the tank will only be flammable at a concentration of about 50% methane or above. Below this level, specialist equipment (sometimes included in the boiler or GCU) or venting of methane to the atmosphere will be required.

Gassing up is complete when the consumers are able to use the gas leaving the LNG tank. Discussions with engine manufacturers suggest that this limit is based on the lower heating value (net calorific value) of the gas, with most manufacturers requiring a value in the range 28-30 MJ/m³ (at 0°C/0°C reference conditions). This corresponds to a methane concentration of about 78% methane and 22% nitrogen. So, with a safety margin added, SGMF considers gassing up to be complete when the nitrogen content of the gas leaving a tank is <20 mol% nitrogen.
9. Working In and On LNG Fuel Tanks

9.1. LNG Fuel Tanks

LNG fuel tanks contain the largest amount of potential hazard on a gas-fuelled vessel so their integrity should be maintained at all times. The design of LNG fuel tanks is defined in Section 6 of the IGF Code. The main types of fuel tank are described briefly in the subsections below.

9.1.1. Type A Tanks

There were no Type A fuel tanks in service or under construction at the start of 2019. However, they are a viable option. A Type A LNG carrier was under construction in China in early 2019.

Type A tanks operate at pressures below 700 mbarg.

Type A tanks are free-standing/self-supporting tanks able to hold LNG but do not have any stress analysis calculations to examine failure scenarios and so require a full secondary barrier. The secondary barrier must be capable of holding the LNG for 15 days. The tank can take any shape necessary to fit into a vessel’s hull.

The outside (insulation) of a Type A tank must be visible from surrounding hull spaces.

9.1.2. Type B Tanks

There were no Type B fuel tanks in service at the start of 2019. An order for LNG-fuelled container vessels during 2019 includes Type B and is under construction for entry into service in 2020/2021.

There are two types of Type B tank within the LNG carrier fleet: firstly, the Moss Rosenberg spherical design, which makes up about 23% of the fleet; and, secondly, the IHI prismatic type where four examples are operating. It is difficult to see a spherical tank used as a fuel tank as the tank would take up a large amount of ship space for a limited fuel volume. However, the prismatic design, which can take any shape necessary to fit into a vessel’s hull could easily be envisaged.
Type B tanks operate at pressures below 700 mbarg.

Like Type A tanks, Type B tanks are free-standing/self-supporting tanks able to hold LNG. However, Type B tanks use stress analysis calculations of failure scenarios to limit the size of the secondary barrier – in some cases to a simple drip tray.

The outside (insulation) of a Type B tank must be visible from surrounding hull spaces.

9.1.3. Type C Tanks

Most of the LNG fuel tanks in service are Type C (152 of 152 vessels in service and 147 of 157 vessels on order in mid-2019). These tanks are designed and tested as pressure vessels and operate at pressures above 2 bar on natural gas/LNG systems. This means that no secondary barrier is required. Because Type C tanks are pressure vessels, the BOG generated from heat ingress can be allowed to build up and pressurise the tank. The hold time of a Type C will be determined by its insulation (heat ingress) and pressure relief valve settings, but all tanks will exceed the 15-day limit set by the IGF Code.

Most Type C tanks are made of 9% nickel steel as this is more economical than some stainless steel, although tanks in this material exist. Pressure vessels are relatively heavy and, being cylindrical in design, do not fit efficiently into rectangular spaces in vessel hulls. Because of this they are restricted in size. The largest Type C tanks known to be in service are of up to 1,800 m³ capacity each on the car carrier Siem Confucius; some cruise ships are proposing to use tanks with a capacity of 2,400 m³. Smaller pressure vessels can be workshop produced and are therefore cost efficient and are regularly employed on coastal and shorter international routes.

There are two types of Type C tank, defined by how they are insulated:

- externally insulated tanks, which use a foam insulation
- vacuum-insulated tanks (VIT), which have an outer jacket held under a very low (vacuum) pressure
The IGF Code treats all types of Type C tanks the same – that is, the design criteria for vacuum-insulated tanks are the same for externally foam clad tanks. Any differences in the required fatigue design or allowable crack propagation which determine inspection and maintenance criteria must be clearly stated.

9.1.4. Membrane-Type Tanks
Membrane-type fuel tanks consist of two layers of LNG-proof barrier with insulation between the two barriers and between the outer secondary barrier and the inner hull structure. The primary barrier (in contact with LNG) consists of thin metallic sheets. Membrane-type tanks dominate the LNG carrier business.
The tank insulation spaces are filled with nitrogen to prevent any mixing of air and gas should the membrane leak. Nitrogen is continuously monitored for methane to detect leaks of bulk LNG through the primary barrier. The spent nitrogen exits via a dedicated vent system.

The membrane tanks currently in use typically operate at about 200 mbarg but can be pressurised up to 700 mbarg. A new generation of membrane tanks allows greater pressurisation.

Membrane tanks are able to achieve a holding time of 15 days by using an active BOG management system, as required by IGF Code.

Membrane tank licensor GTT is very specific about how a tank should be repaired and requires its previously approved contractors to be involved.

*Figure 9.2: Inside the membrane-type LNG tank of a CMA CGM 23,000 TEU containership (©CMA CGM)*
9.1.5. **Removable Tanks**

One option for fuel supply is to use an ISO container (a containerised tank) as a portable fuel tank. The tank is brought onboard the vessel full of LNG and when empty is replaced by another full container.

This type of tank can be removed (whatever its fill condition) before maintenance to remove fuel from the ship. However, removal of the tank does not ensure that the vessel is totally gas-free. Any LNG and/or gas in the fuel preparation and delivery system still needs to be removed by purging and venting/incineration.

The connections between the vessel and temporary tank will need to be protected during maintenance work, as follows:

- end caps should be used to close off the ends of the transfer hoses to prevent ingress of dust, debris and moisture
- hoses should be protected from dropped objects, human feet, welding splatter, and so on
- hoses should not be coiled tighter than the manufacturer’s recommendation as this will reduce hose life
- removable tank connections to the vent mast may need to be sealed during maintenance to allow continued use of the vent system

9.2. **Fuel Tank Failure Modes**

LNG fuel tanks contain the largest volume of potential hazard on a gas-fuelled vessel. Their continued integrity is therefore of prime importance. This needs to be confirmed by appropriate maintenance and inspection regimes carried out at timely intervals.

The primary failure mechanism for a tank is a defect in the base metal, or more likely the weld material, growing in size (propagating) to become a crack of a defined size that endangers the tank and the vessel.
Stress leading to defects (and later cracks) within LNG fuel tanks is likely to be caused by:

- poor initial fabrication and ineffective non-destructive testing
- exceeding fatigue limits through long-term operation
- external damage (collision with another vessel, dropped object and so on)
- overfilling of tanks
- over-pressurisation of the tank and the opening of the pressure-relief valves
- tank temperature differential (for example, temperature in the roof of the tank compared with the base of the tank) exceeding a manufacturer’s defined value
- corrosion, particularly under the insulation on the outside of the tank
- sloshing and wave damage to the tanks or their supporting structures

### 9.3. Fuel Tank Inspection

The IGF Code (6.4.1.8) requires an inspection/survey plan for the liquefied gas fuel containment system that has been developed and approved by the administration and used throughout the life of the tank (IGF Code 18.3.2).

This inspection/survey plan should identify aspects to be examined and/or validated during surveys throughout the life of the liquefied gas fuel containment system. In particular, the plan should identify any necessary in-service survey, maintenance and testing that was assumed when liquefied gas fuel containment system design parameters were selected.

The inspection/survey plan may include specific critical locations for fatigue life (6.4.12.2.8) or locations that are difficult to inspect (6.4.12.2.9).

Classification Societies normally propose two elements in an inspection/survey plan: firstly, an external inspection of the tank on an annual basis as part of a continuous survey regime; and, secondly, an internal inspection of the tank as part of the special survey programme during dry docking.
Despite IACS providing an overarching document for fuel tank inspection, there is no agreed approach across all Class Societies about how inspection/survey plans should be carried out.

External and internal inspections are covered in the next two sections.

9.4. **External Tank Inspection**

All LNG fuel tanks require an external inspection that looks at the tank insulation (cold spots) and, for non-membrane tanks, the support saddles/blocks that hold them in place.

External inspection requirements are defined by the Class Societies in IACS UR Z 25 and should be performed at least every 12 months. The inspection should include the following:

- external examination of the storage tanks, including the secondary barrier if fitted and accessible
- general examination of the space in which the fuel storage is located
- external examination of the tank pressure and vacuum-relief valves
- verification of satisfactory operation of the tank-monitoring system
- testing of remote and local closing of the installed main tank valves
- internal examination of the tank connection space
- examination and testing of installed bilge alarms and means of drainage of the compartment

Leaks in LNG fuel tanks can be detected by regular thermographs and potentially by appropriately located thermocouples. Failure of insulation or cold paths through the tank shell/insulation can be seen visually through condensation and will be obvious through thermography.

If primary and secondary barriers are installed, for example in a membrane type tank, gas detection or over pressure between the barriers can be used to detect leaks. The functioning of the high-level tank alarm also needs to be tested.
9.5. Internal Tank Inspection

Because LNG fuel tanks contain the largest volume of potential hazard on a gas-fuelled vessel, their integrity should be maintained at all times. IACS provides a unified requirement (Z25) for all Class Societies to follow regarding internal inspection. However, discussions with Class Societies during 2018 and 2019 clearly indicate that Class and individual surveyors are interpreting the document in very different ways, when it comes to inspecting Type C tanks. It should be made clear by Class Societies, prior to dry-docking, why an internal tank inspection is required. If there is no valid engineering/best practice explanation, an internal inspection should not be carried out.

If an internal inspection of a type C tank does take place, having the tank builder/OEM present will help to ensure that the tank is returned to full performance – for example, regarding insulation integrity – after inspection.

Most Class Societies do not inspect vacuum-insulated Type C tanks, despite there being no difference in the IGF Code between vacuum-based and foam-based insulation systems.

The increasing use of continuous (“digital”) classification is also allowing changes in inspection practice – Risk-based inspection (RBI) – to become more common. Continuous monitoring of the inter-barrier spaces of a membrane-type tank is an example of continuous assessment without the need for internal inspection.

**Inspection of LNG Tanks at Onshore Facilities**

The EEMUA (Engineering Equipment and Materials User Association) – in its standard for onshore LNG tanks (EEMUA 159:2003) – states: “No technical justification for conducting routine internal inspections of LNG tanks can be provided so long as the tanks are operated within their design/operational limitations that should be confirmed by the external inspection and the operating history.”
Class Societies/surveyors are allowed to issue “waivers” should certain (unpublished) criteria be met. In some parts of the bulk LNG industry – for example, Floating Storage and Regasification Units (FSRU) and Floating Liquefaction (FLNG) – waivers are common.

Waivers may be sought on the basis that entering a LNG tank may:

- damage the tank (particularly in the case of membrane tanks)
- reduce or remove the effectiveness of vacuum-insulation by breaking the vacuum seal
- break a gas-tight seal
- create greenhouse gas emissions (CO₂ and CH₄) from gas freeing and gassing up

For a waiver to be granted, additional evidence of continuing good performance – such as operational parameter reporting or external inspection of the LNG fuel tanks – may be required. For example:

- infrared thermography with LNG in the fuel tank to detect cold spots
- temperature, pressure and level measurements
- recording of tank mal-performance events
- proof that the primary barrier of a membrane tank is leak-tight by continuous monitoring for methane concentrations in the inter-barrier nitrogen sweep gas
- for membrane tanks (SBTT test) by pulling a vacuum across the secondary barrier and measuring the leakage rate (if any) with the tank gassed up and warm but therefore empty of LNG

Waivers are inappropriate if the LNG fuel tanks:

- show signs of leakage
- have been over-pressurised or operated at vacuum
- have been externally damaged
In these instances, internal inspections should be performed. If entry to a tank is required for pump replacement, simultaneous inspection should be encouraged to avoid a second inspection during a special survey.

Where an internal inspection is required, Class Societies (or IACS) should clearly indicate the methods they will use to determine the tank’s remaining fatigue life and to identify any crack propagation behaviour (maximum allowable crack size and location) or other phenomenon that needs remediation.

The problem with the current waiver process is that it is frequently only granted at the time of the special survey, which is too late to avoid the gas-freeing/gassing-up process. Exemptions ahead of time, like those for FSRUs, are required.

An LNG fuel tank is a confined or enclosed space, entry into which will normally be through the roof/top of the vessel. Access and escape may therefore be especially difficult. Section 18.2.1 of the IGF Code recommends that personnel should avoid entering fuel tanks, fuel storage hold spaces, void spaces, tank connection spaces, or other enclosed spaces where gas or flammable vapours may accumulate under normal circumstances. If entry is essential, it should take place only if the gas content of the atmosphere is non-flammable and has sufficient oxygen to support life.

If entry into a fuel tank is necessary, IMO has produced “Revised recommendations for entering enclosed spaces aboard ships (A.1050(27))”, while the International Association of Class Societies (IACS) has Recommendation 72. Between them, these publications cover entry into confined spaces in detail.

Before human entry, the tank must have an atmospheric composition with oxygen present at a level above 20.9% by volume. The tank should be at a temperature above 0°C before ambient air is allowed in to prevent condensation of water vapour in the air on the cold tank surface.

### 9.5.1. Removable Tanks

Removal tanks must be tested to the standards of the national body where the vessel predominantly operates.
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Appendix A: LNG Properties

A1. LNG

LNG is a mixture of hydrocarbons – predominantly methane (80-98%) – in a liquid state. Other significant components are other alkanes: ethane, propane and butane. Nitrogen may also be present at a concentration of up to 1%.

LNG is a liquid fuel produced from natural gas. At normal conditions, atmospheric pressure and ambient temperature, natural gas exists only in the gaseous phase. Liquefied gases are produced by reducing their temperature and increasing their pressure until the gas liquefies. Small amounts of liquid can evaporate into very large volumes of gas. For example, one litre of LNG vaporises to about 600 litres of natural gas when warmed to ambient temperatures.

Bulk LNG is normally stored at atmospheric pressure. To be a liquid at this pressure, natural gas must be cooled to about -162°C (or -262°F). On LNG-fuelled ships LNG is stored at higher pressures, typically up to 4-5 barg. At these pressures LNG remains liquid at higher temperatures. However, all of these temperatures are very cold – for example, the boiling point of LNG at 4 barg (5 bara) is -138°C.

As a liquid, LNG is relatively non-hazardous, neither flammable nor toxic. It is also colourless and odourless. LNG’s cryogenic temperature does present hazards in that personnel can be harmed and most materials, including ship hull steels, can be damaged if they accidentally come into contact with LNG.

No matter how well an LNG’s container is insulated, some heat will transfer into the LNG, causing some of it to vaporise. This vapour is flammable so its behaviour defines the required size of the hazardous zone and the safety-sensitive area.

A2. Boil-Off Gas and Natural Gas

Vapour generated from evaporating LNG is called Boil-Off Gas (BOG). This vapour is very similar to natural gas (NG). The phrase “vapour return” denotes the gas in an LNG storage tank that is being displaced by LNG.
during bunkering and flowing from the gas-fuelled ship back to the LNG supplier. Vapour return is just BOG flowing from one tank to another.

BOG, being natural gas, is colourless and odourless. Pipeline natural gas has a smell added to allow leaks to be easily detected. This is not so with LNG. The odorant used for pipeline natural gas would freeze if put into the LNG and be ineffective.

Because BOG and natural gas are flammable, their behaviour can define the required size of the hazardous zone and the safety-sensitive area.

**A3. LNG Leak Behaviour**

LNG leakage behaviour is primarily controlled by two factors:

- the pressure of the leak source
- the size of the hole from which the leak is occurring

If the leak has pressure behind it, the LNG will spray out. The higher the pressure, the greater the length of the jet. The outside of the jet will mix vigorously with the air and vaporise. However, the centre of the jet will not mix with air and may be so limited in the amount of heat it can absorb that it remains as LNG. As gravity exerts its pull, droplets of LNG will fall out of the jet onto the surface below. This is how LNG is expected to behave at the storage pressures in Type C tanks onboard gas-fuelled ships, in road tankers, and in systems that use pumps to transfer LNG.

If there is no pressure behind the leak, the LNG will flow downwards under the force of gravity. The rate of the LNG leak will determine how the LNG behaves and how much, if any, reaches the surface below the leak source. If the LNG leak is small, the LNG will probably vaporise before it hits the ground. These small leaks will be hard to detect. Higher flow rate leaks will form pools. Pool size will be determined by how fast the pool is warmed by absorbing heat from the surface (water, steel of the ship, earth/concrete, and so on) under the pool when compared with how much LNG is entering the pool.
The rate at which LNG vaporises is primarily determined by heat transfer from the immediate surroundings. Atmospheric conditions have a secondary affect. To vaporise, LNG needs energy (heat); the rate of vaporisation depends on how quickly this heat can be supplied. Poorly conducting solid materials, such as earth or concrete, can provide considerable heat initially but after the first few seconds, once the immediate ground surface has been cooled, the transfer rate will slow because of the time it takes for heat to conduct through the solid material. Metals, such as ship decks, are much better heat conductors than the ground and so can supply heat more quickly to the LNG. However, they remain relatively limited in their capacity to vaporise LNG.

The steels used for shipbuilding become brittle and fracture at LNG temperatures. This typically results in the cracking of decks and structures. However, it is very unlikely that the structural integrity of the vessel will be affected sufficiently to cause loss.

Figure A1: Brittle fracture caused by an LNG spill

In most circumstances the spilling of LNG onto water will result in the formation of a pool on the surface, similar to its behaviour on land. For any sizeable spill, the size of the pool on water will be smaller than on land, as it evaporates faster. However, if the LNG and water are able to mix quickly, the resulting heat transfer can allow the LNG to boil so rapidly that the resulting gas creates a localised, high-pressure blast wave as it expands. This phenomenon is called a Rapid Phase Transition, or RPT.
Dry air is not a particularly good conductor of heat. The dispersion of LNG vapour (and any very small droplets within the cloud) and BOG can be significantly affected by the weather. A key factor is how rapidly they warm and become buoyant. This will be affected by:

- wind – as higher wind speeds cause more turbulence in the cloud, mixing it faster and diluting it
- atmospheric temperature
- the degree of humidity as the water vapour in the air will release latent heat as it condenses; this condensation also makes the cloud visible

(Note: White clouds of water particles do not solely result from LNG leaks. Any source of cold – for example, a bunkering hose or LNG transfer system – may cause localised condensation.)

Methane, the primary constituent of LNG or natural gas, is a small molecule, lighter than the main constituents of air; the molecular weight of methane is 16, nitrogen 28 and oxygen 32. So, in normal conditions, methane is lighter (less dense) than air and will rise.

However, density is strongly affected by temperature. The lower the temperature, the greater the density. As LNG, BOG and natural gas are very cold immediately after vaporisation (say at <-150°C) their density at atmospheric pressure is high: about two-to-three times greater than air at ambient temperature (of say 20°C). Therefore, around the leak, the LNG/BOG/NG will be heavier (denser) than air and will flow towards the ground, water surface or deck level. The BOG/natural gas will not be lighter than air until it has warmed to above about -110°C (~166°F). This is normally some distance from the leak source.
A4. Ignition Scenarios

Within the gas cloud there is potentially a flammable mixture of BOG/natural gas that can be ignited if the conditions are conducive. For a fire to occur there must be three components present:

- fuel (the vapour above the LNG or natural gas)
- oxidant (air or oxygen mixed in the correct proportion) and
- energy (a spark or high temperature)

The flashpoint of liquefied methane, the temperature at which the vapour generated by the liquid will ignite, is -187°C. Therefore in any LNG storage, transfer or operational scenario, LNG or natural gas may ignite if the fuel-air mixture is correct and there is sufficient energy to cause ignition.

Methane (natural gas) is only flammable within a certain concentration range in air (Figure A3). If there is too much methane, the flame will not be able to get enough oxygen and will go out. If there is too little fuel, again the flame will go out. These limiting conditions are called the Lower and Upper Flammable/Explosive Limits (LFL/LEL and UFL/UEL). The flammability range of methane (or LNG vapour/natural gas) in air is between 5% (LFL) and 15% (UFL).
Methane can spontaneously ignite if it is heated to above its auto-ignition temperature, about 530°C (980°F). This contrasts with fuel oils, which have typical auto-ignition temperatures of around 250°C and can therefore be readily ignited by hot surfaces such as unlagged exhaust systems, resulting in engine room fires. Auto-ignition of any vapour is unlikely on a gas-fuelled vessel.

**Figure A3: Flammability limits of methane (LNG/natural gas)**

Three types of fire are possible with LNG/natural gas systems. These fire types depend on the quality of the fuel, in effect whether the bulk of the fuel is gaseous or liquid, and secondly the pressure associated with the leak scenario. The three scenarios are described in Table A3.

### A5. LNG Fires

The thermal radiation given off from a fire is a threat to human health and can degrade and damage structural materials sufficiently to result in failure and potential escalation of the fire to other areas/systems. Thermal radiation is therefore a key parameter in determining safe distances from LNG/natural gas hazards.

Three types of fire are possible with LNG/natural gas systems. These fire types depend on the quality of the fuel, in effect whether the bulk of the fuel is gaseous or liquid, and secondly the pressure associated with the leak scenario. The three scenarios are described in Table A3.
### Table A3: LNG fires

<table>
<thead>
<tr>
<th>Fire Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool</td>
<td>A fire burning over a pool of LNG. For leaks from LNG facilities that are relatively small (perhaps a few cubic metres) a bright, clean-burning flame is expected with high luminosity and very high thermal radiation levels. Pool fires are highly localised.</td>
</tr>
<tr>
<td>Jet</td>
<td>A fire associated with pressurised releases of gas, liquid or a mixture of the two. The behaviour of a jet fire depends on the flow rate of the material in the jet. Liquid droplets may “rain out” of the jet onto the ground/water/deck surface, where they will burn as pool fires. The thermal radiation from a jet fire will be significantly higher than for pool fires. The thermal flux from a jet fire – and in extreme cases, the impact of cryogenic LNG droplets in the core of the jet – is likely to cause rapid damage and failure of surrounding unprotected structures and equipment. Again, although larger than pool fires, jet fires are localised.</td>
</tr>
<tr>
<td>Flash</td>
<td>The combustion of a vapour cloud without generation of any significant pressure. A flash fire occurs when a cloud of flammable gas in an open area is ignited. An open area does not constrain the gas, allowing it to expand without restriction. In a flash fire the gas cloud will combust (“flash back”) from the point of ignition back to the source of the leak, combusting all the gas present in the flammable range (LFL to UFL) and then burning at the UFL boundary until all the hydrocarbon fuel in the cloud has been consumed. The fire will then become a jet fire or pool fire, depending on the leak source.</td>
</tr>
</tbody>
</table>
A6. Explosions

There is the potential for a drifting vapour cloud to enter an enclosed area, buildings, rooms or other confined areas, such as drains. If the flash fire burns into these areas, the gas can no longer expand and accelerates instead, potentially causing an explosion. Forced ventilation of enclosed areas can be used to ensure that the methane never reaches its flammable range.

Blast over-pressures from methane explosions (deflagrations) can be significant. However, the blast pressure falls rapidly with distance so explosions are primarily concerned with distances close to or within the gas-fuelled vessel or building.

Another type of explosion is known as a BLEVE (Boiling Liquid Expanding Vapour Explosion). Here, a strong heat source, normally a fire, heats up and boils LNG within a pressure vessel, such as a Type C tank. The tank pressurises and gas is released through the pressure-relief system. If the fire is intense enough, the pressure-relief valves may not be of sufficient capacity to vent gas quickly enough to control the tank pressure. Eventually the tank will rupture, creating a fireball and high-velocity missiles. Failure can be quicker if the flames impinge on an area of tank where there is gas rather than LNG, as the lack of boiling allows a faster temperature rise, weakening the steel in the immediate area.

BLEVEs are major events which can impact a wide area. However, they take time to develop, allowing an emergency response to cool the vessel or to extinguish the fire and/or to evacuate the area.

A7. Other Hazard Scenarios

Asphyxiation (oxygen deficiency)
Within a leaking LNG/gas vapour cloud, or within a space flooded with escaping vapour, the amount of air may be reduced and replaced by the heavier cold methane, which will disperse only slowly. Oxygen levels will reduce, impairing human mental performance. Initially, there is mental
confusion (disorientation and inability to think straight), loss of muscle movement (clumsiness), emotional/mood changes and loss of sensation. This is followed by unconsciousness and ultimately death.

**Cryogenic burns and impacts**

Human flesh can be damaged if it comes into contact either directly with LNG or indirectly through uninsulated pipework. Brief exposures that would not affect skin on the face or hands can damage delicate tissues such as the eyes. Prolonged exposure of the skin or contact with cold surfaces can cause frostbite. The skin appears waxy yellow. There is no initial pain, but there is intense pain when frozen tissue thaws.

Unprotected skin can stick to metal cooled by cryogenic liquids. The skin can then tear when pulled away. Even non-metallic materials are dangerous to touch at low temperatures. Prolonged breathing of extremely cold air may damage the lungs.
Appendix B: Risk Assessment

B1. Risk

A risk is the likelihood of an event occurring at any particular time that will have consequences on people, property and/or the environment. Generally, risks are considered as negative – for example, the risk of a horse in a race coming last.

Risk therefore has two components: a time-based frequency, or probability, and a physical consequence.

For example, in the UK the risk of being killed in a road accident is statistically 1 in 10,000 each year. The consequence is the death of an individual; the frequency is written mathematically as $1 \times 10^{-4}$ (1/10,000) per year. Many people will have been involved in a road accident or know somebody who has. Many risks, however, are extremely rare and may not be seen in an individual’s lifetime. These risks often have much larger consequences, perhaps the killing of many people. For example, the failure of a LNG piping system will be very rare compared with a slip or fall. This chapter primarily considers these larger and much less frequent “major accident risks”.

Risks can be described on an individual level, as in the road accident example above, or across many people from a group of individuals, to a whole city, or even a whole country. This is called societal risk and is often represented by a frequency-number of fatalities (F-N) curve, which shows the probability of killing a number of people. Risk assessment varies by country (as in federal systems) and may vary more locally (as in state-based systems). For example, France will have different tolerances for risk compared with the Netherlands or the USA; so the relevant authorities should be consulted to understand what is acceptable at a particular maintenance location before any work begins.

A Safety Management System (SMS) is about ensuring the safe and environmentally responsible operation of ships and bunkering facilities. An SMS therefore requires companies to plan an approach to Health, Safety and Environmental (HSE) matters, setting out priorities and objectives that reduce risks whenever possible. A risk assessment process is therefore required to identify, prioritise and mitigate these risks for effective safety management on a continuous basis.
B2. Risk Assessment

A risk assessment process identifies and quantifies risks so that they can be compared with legislation, regulation and human resources norms to determine their acceptability (or tolerability). If the risks are not acceptable, the assessment identifies mitigations to reduce the consequences and/or likelihood of the risks until the level of risk is deemed acceptable or all risk reduction options have been exhausted. In the latter case, the activity is deemed to present intolerable risks and so would not be allowed.

The many methods of risk assessment that are available are described in various international standards, including:

<table>
<thead>
<tr>
<th>ISO 17776</th>
<th>Petroleum and natural gas industries – Offshore production installations – Major accident hazard management during the design of new installations</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 31000</td>
<td>Risk Management – Principles and Guidelines</td>
</tr>
<tr>
<td>ISO 31010</td>
<td>Risk Management – Risk Assessment Techniques</td>
</tr>
<tr>
<td>ISO 16901</td>
<td>Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface</td>
</tr>
<tr>
<td>ISO 18683</td>
<td>Guidelines for systems and installations for supply of LNG as fuel to ships</td>
</tr>
<tr>
<td>ISO 45001</td>
<td>Occupational Health and Safety</td>
</tr>
<tr>
<td>IACS 127</td>
<td>A guide to risk assessment in ship operations</td>
</tr>
<tr>
<td>IACS 146</td>
<td>Risk assessment as required by the IGF Code</td>
</tr>
</tbody>
</table>

However, none of these standards deal with maintenance and its very specific additional hazards. There has been some guidance produced for the offshore oil and gas industries, such as Oil & Gas UK’s “Guidance on the Conduct of Operational Risk Assessment for the UKCS Offshore Oil and Gas Operations”, which provides advice on safety management systems.

A risk assessment and management process is shown in flowchart Figure B1 below. This is for standard operations but is equally applicable to maintenance so long as the absence of normal services is considered as part of the risk identification and mitigation processes.
The level and extent of hazard identification and risk assessment activities vary depending on: the scale of the installation; and the stage in the installation life cycle when the identification and assessment process is undertaken.

- in many circumstances, the knowledge and expertise of experienced staff using a structured approach may be sufficient to manage risk, particularly for repeat designs – for example, subsequent vessels in a series.
• structured review techniques can be used to identify and evaluate previously unforeseen hazards and unintended events that are not adequately addressed by the previous methods.
• checklists and international standards can confirm compliance with some risks but do not identify location- or vessel-specific risks.

Risk assessment comprises four steps:

• identify what can go wrong (identify the dangers or hazards)
• assess their effects (identify the consequences/impacts of the risk)
• assess the likelihood/frequency
• decide whether the risk is tolerable; if not, identify risk-reducing measures (mitigations)

Each step is explained in more detail in the following sections.

**B3. Risk Identification**

A risk cannot be mitigated or managed until it has first been identified. Risk identification therefore needs to be a structured process, involving multiple individuals, to identify all the risks. There are many ways of identifying and quantifying risks.

There are two concerns during maintenance:

• firstly, whether the risks identified by the original risk identification process are still mitigated during the maintenance work; and
• secondly, are there any new risks presented by the maintenance practices and tools being employed.

Existing risks should have been identified by HAZID and HAZOP studies during the vessel’s design and construction. However, a vessel’s design may have changed over time – because of modifications and previous maintenance activities – so the current applicability of these studies needs to be confirmed.
HAZID and HAZOP processes are the most common studies but many other methods are available. Most of the comments provided on HAZID and HAZOP are also appropriate to the other techniques. HAZID and HAZOP studies and their management are described in the box below.

HAZID & HAZOP

HAZIDs/HAZOPs are normally performed as workshops during which an experienced team – managed by an independent chairman and recorded by a dedicated scribe – brainstorms hazards for one or more operations using a series of keywords. For each hazard, barriers/mitigations that impact either the likelihood or consequence are recorded.

A HAZID/HAZOP workshop should encourage everyone to contribute to ensure the maximum chance that all hazards are identified. To assist this, a few simple rules are worth applying:

- break the scope down into manageable chunks, called nodes, to assist thinking but note other ideas and review them at a more appropriate time – nodes might be:
  - by activity for example, sailing; bunkering; cargo operations and dry-docking
  - by equipment/vessel area for example LNG storage tank; PBU and vaporiser; gas supply to and use of engines, generators and boilers; and tank connection space and fuel preparation room ventilation systems; cargo systems and so on
- limit the duration of each session to maintain the effectiveness of the team by scheduling frequent breaks
- no idea is too trivial or silly – such ideas often result in the longest discussions and identify risks that are otherwise overlooked
- all ideas should be recorded
- limit discussion to one conversation at a time so that everybody hears everything
- make sure everyone contributes, particularly if some members are more experienced or confident and tend to dominate
Preparation is important to get the best out of a team over a short period of time. Providing documents and keywords in advance may stimulate better discussions.

An experienced team should be assembled whenever possible. To be effective, the size of the team needs to be relatively small, otherwise individuals may feel inhibited from taking part; a typical team size is 8-10 people.

The workshop must be formally recorded. The output should include:

- an overview of the workshop, including where and when held, individuals present, underlying design, information and assumptions, and keywords used
- assessment of each risk identified
- any actions to resolve a lack of data which prevents full assessment, or deficiencies within the design, identifying which individual/role or department has been assigned to provide a resolution

The environmental equivalent of a HAZID is called an ENVID (ENVironmental impact IDENTification) and uses the same process but different keywords. HAZIDs and ENVIDs often happen simultaneously. Similarly a HAZCON (HAZard in CONstruction) study is the construction and maintenance equivalent of a HAZOP.

Table B1 below shows an extract from a gas-fuelled vessel HAZID. One of the mitigations under item 1 is the use of a flammable gas-detection and alarm system. This system may be under maintenance itself or be disabled or compromised because previous maintenance activities – for example, certain dusts and greases – may have impaired its performance. Other safeguards potentially impacted by maintenance are shown in orange.
## Table B1: Example of a HAZID output

<table>
<thead>
<tr>
<th>Node</th>
<th>Keyword</th>
<th>Causes</th>
<th>Consequences</th>
<th>Safeguards (mitigations)</th>
<th>Impact</th>
<th>Likelihood</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LNG tank</td>
<td>Equipment failure</td>
<td>Material/weld failure of inner tank</td>
<td>Release of LNG/gas into tank insulation and/or tank space</td>
<td>Tank design approved by Class Ventilation system to prevent gas build-up Zone 1 rated electrical equipment Gas detection and alarm</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>LNG tank</td>
<td>Equipment failure</td>
<td>Damage to external tank Material/weld failure of outer tank</td>
<td>Loss of vacuum insulation around tank, leading to heat ingress Increased LNG vaporisation, leading to tank pressurisation Venting of gas Rupture of tank</td>
<td>Perlite insulation in void space reduces impact of vacuum loss Periodic checks for cold spots Periodic checks of vacuum strength Multiple relief valves on inner tank Monitoring of LNG tank pressure</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>LNG tank</td>
<td>Control system – pressure sensor failure</td>
<td>Loss of information about tank conditions Potential loss of alarm or trip function</td>
<td>First indication of overpressure would be relief valves lifting Gas-management plan compromised</td>
<td>Multiple sensors installed Manual monitoring of local gauges</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Node</td>
<td>Keyword</td>
<td>Causes</td>
<td>Consequences</td>
<td>Safeguards (mitigations)</td>
<td>Impact</td>
<td>Likelihood</td>
<td>Actions</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
<td>--------</td>
<td>--------------</td>
<td>-------------------------</td>
<td>--------</td>
<td>------------</td>
<td>---------</td>
</tr>
</tbody>
</table>
| 4    | LNG tank | Operating parameters | Wear to valve seat  
Ice in valve seat | Loss of isolation – valve fails to close properly, allowing gas/LNG to leak into a neighbouring section | Local pressure indication  
Gas detection and alarm  
Moisture control processes  
Valve maintenance | Medium | Medium |   |
| 5    | LNG tank | Utility loss | Inability to open/close valves | Gas-management plan may be compromised  
Valve position change to fail-safe – temporary isolation may be lost | Isolation of air on valves used as temporary isolations  
Air receiver for limited time operation | Medium | Low |   |
| 6    | Utility systems | Power loss | Loss of control system functionality  
Loss of electrical power and lighting | All systems move to fail-safe mode  
Lighting reduced or absent, making access and escape more difficult | Critical control systems operate on back-up power and Uninterruptible Power Supply (UPS)  
Emergency lighting | High | Low |   |
A non-exhaustive list of new risks that may arise from the maintenance process includes:

- the introduction of sparking electrical equipment (such as tools) or equipment being operated or tested without full spark protection (for example, cover removed or re-assembled with gasket damage)
- failure to re-establish gas-tight seals after maintenance
- damage from dropped objects and poor mechanical handling
- asphyxiation from gas leaks, poor purging processes or inappropriate entry into confined spaces
- loss of control and alarm systems or their failure to operate correctly (for example, pressure-relief or control valves removed, control system overrides used, software upgrades and modifications)
- removal or loss of function of fixed monitoring equipment (such as gauges and flammable gas sensors)
- loss of ventilation
- loss of utility (such as instrument air, nitrogen, cooling water and electricity), preventing systems from working correctly
- difficult access to work areas at height and behind instruments, piping and cabling
- vaporisation of trapped and in-tank LNG, leading to system pressurisation
- failure of isolation or purging, leading to the generation or continuation of a flammable-gas atmosphere
- inability to procure suitable spares or the use of materials and equipment with incorrect specifications
- use of hazardous or toxic materials, such as solvents, paints and greases
- exposure to cryogenic hazards after removal of insulation
- insufficient or no flow to keep spaces purged or instrumentation operating correctly
- new flow/leak paths created by conventional and protected/alarmed routes being unavailable (isolated)
Humans and management systems can also fail during maintenance, increasing risks through:

- lack of knowledge/training
- poor briefing/communication and supervision
- failure to follow procedures/instructions
- use of the wrong tools
- poor work quality
- the presence of increased numbers of workers
- an inability to deal effectively with SIMOPs

B4. Risk Mitigation

Risk management and mitigation is all about placing barriers between threats and the consequences.

**Threats** A threat is an event that has the potential to cause a hazard.

**Hazards** A hazard is an event that has the potential to cause harm or damage – for example, an LNG or gas leak.

**Consequences** Consequences are the potential outcomes if a hazard occurs. Consequences include:

- safety issues – loss of life or injury
- environmental damage – pollution
- reputational loss, including:
  - damage to public/community relations
  - lowering of share price
  - loss of opportunities
- financial loss
**Barriers**  Barriers are actions, policies, physical design features and/or active and passive safety systems which stop a threat leading to a hazard or hazard turning into a consequence.

Gas-fuelled vessels are designed to contain threats through the placement of various barriers. There are primarily three types:

- **personnel** – for example, ensuring competency by appropriate training
- **procedures and processes** – for example, a safety management system such as a mechanical handling procedure and checklist (barrier) to prevent an item of cargo being dropped on a gas-live system (threat)
- **engineering/equipment/technology** – for example, a pressure-relief valve (barrier) that lifts when a certain pressure is reached, preventing any further increase (threat)

Barriers also exist for consequences. For example:

- a drip tray (barrier) stops LNG hitting a steel deck structure, causing it to undergo brittle fracture (consequence)
- training of personnel (barrier) to stop an LNG leak (consequence) as fast as possible

Mitigating or reducing risk is about putting the right barriers – both physical and procedural – in the right place at the right time.

The “bow-tie” method is used as an example, primarily because it provides a good visualisation of how things might go wrong, and the causes and consequences (Figure B2). With the hazard (a single point) in the centre, and multiple causes/threats to the left and consequences to the right, the figure resembles a bow tie. The mitigations/barriers/control measures employed for each major hazard can then be added, all within a single diagram. Though not essential, it can aid understanding of how the threats of gas/LNG are managed.
Other risk mitigation methods are available and should lead to the same conclusions. These are described in SGMF’s “bunkering guidelines (FP07-1)”.

*Figure B2: An example of a bow-tie diagram*

For a gas-fuelled vessel, the threats and consequences that need to be considered for maintenance – in addition to those for a conventionally fuelled ship – concern the presence of LNG and/or natural gas onboard the vessel.

Maintenance may fully or partially remove or override one or more of the barriers that would otherwise be in place, resulting in potential reductions in risk mitigation and therefore increasing the likelihood of an accident occurring and/or the consequences of an accident.

Whether additional or replacement mitigations will be required will depend on the level of the remaining risk and whether it is acceptable (tolerable) to the shipowner, the maintenance staff and the competent authority (see Figure B1). The risk assessment industry uses the term ALARP (As Low As Reasonably Practicable) in Europe and ALARA (As Low As Reasonably Achievable) in the USA to define whether further risk reduction is required. “Reasonably Practicable” involves weighing up the magnitude of the remaining risk against the time, trouble and cost of further measures to control risk. The UK Health & Safety Executive gives two extreme examples, paraphrased below:

- to spend UK£1 million to prevent five staff suffering bruised knees
is obviously grossly disproportionate, because the harm is very low compared with the required investment

- to spend UK£1 million to prevent a major explosion that could kill 150 people is obviously proportionate

In most scenarios, the need to spend additional time, money and resources is less clear-cut.

Figure B3: The ALARP principle

- Risk cannot be justified except in extraordinary circumstances
- Risk is tolerable only if further risk reduction is impractical
- Risk sufficiently low to be generally acceptable
- Risk reduction required regardless of cost
- ALARP principles apply to risk improvement
- Good practice

Figure B4 and Table B2 provide examples of barriers frequently used for threat mitigation and how these might be impacted by maintenance activities. Similarly, Figure B5 and Table B3 provide examples of barriers for common consequences.
**Figure B4: Mitigation of threats**

**Table B2: Impact of maintenance on the mitigation of threats**

<table>
<thead>
<tr>
<th>Threat</th>
<th>Barrier</th>
<th>Compromising impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relief valve lifts</td>
<td>Vent system and mast</td>
<td>Maintenance of the vent system leads to incorrect operation</td>
</tr>
<tr>
<td></td>
<td>Working procedure</td>
<td>Over-pressurisation of a vessel or piping system because of a poor gas-management plan</td>
</tr>
<tr>
<td></td>
<td>Inadequate draining and purging, leading to trapped LNG vaporising</td>
<td></td>
</tr>
</tbody>
</table>
### Table B2: Impact of maintenance on the mitigation of threats (continued)

<table>
<thead>
<tr>
<th>Threat</th>
<th>Barrier</th>
<th>Compromising impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human error</td>
<td>Work definition and supervision</td>
<td>Reading the wrong instrumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Draining of a hydraulic system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Removal of wrong or too much cryogenic insulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cutting into or removing an isolation from a purging (N_2) system</td>
</tr>
<tr>
<td>Training and competence</td>
<td></td>
<td>Poor re-assembly of zoned electrical equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using the wrong tools</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blocking a ventilation system</td>
</tr>
<tr>
<td>Permit-to-work system</td>
<td></td>
<td>Opening/closing of the wrong valve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using/removing the wrong pipe/isolation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolating the wrong instrument or power supply</td>
</tr>
<tr>
<td>System damage</td>
<td>Protective systems</td>
<td>Dropped object/impact</td>
</tr>
<tr>
<td></td>
<td>Working procedure</td>
<td>Mechanical handling/lifting plan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Controlled heating and cooling to accommodate expansion/contraction</td>
</tr>
<tr>
<td></td>
<td>Work definition and supervision</td>
<td>Cutting/grinding of the wrong piping/cabling/system or structural component</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-pressurisation of a system during testing</td>
</tr>
<tr>
<td></td>
<td>Cleanliness and corrosion</td>
<td>Use of wrong materials</td>
</tr>
<tr>
<td>Threat</td>
<td>Barrier</td>
<td>Compromising impact</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Control failure     | Protective systems                  | Disabling of alarm and trip functions  
De-activation of the ESD system or one of its parts – for example, an ESDV                        |
|                     | Work definition and supervision     | Removal of actuator or power/air supply  
Removal of instrument power supply/signal  
Instrument protected from maintenance activity in such a way that it no longer functions correctly, for example gas detector inlet not blocked  
Belief in an Instrument that is no longer calibrated correctly or not working correctly from wear and tear |
|                     | Cleanliness and corrosion            | Dirt and/or debris and/or grease preventing an instrument from operating correctly                                                                 |
|                     | Work definition and supervision     | General or specific power failure  
Software upgrade without equipment-specific patches                                                                                                   |
Figure B5: Mitigation of consequences

- LNG/Gas
  - Training and Competence
  - Equipment insulation
  - Use of suitable materials
  - Use of insulated PPE
  - Use of insulated equipment
  - Use of insulated zoned electrical equipment
  - Use of insulated no naked flames or hot work
  - Use of insulated ventilation of hazardous areas
  - Use of insulated work planning and management
  - Use of insulated active BOG management
  - Use of insulated confined space entry procedures
  - Use of insulated atmosphere monitoring
  - Use of insulated atmosphere monitoring
  - Use of insulated isolation philosophy

- Cold injury/fatality
- Cold embrittlement
- Fire and/or explosion
- Greenhouse gas release
- Asphyxiation

Leak

Confined space entry procedures

Atmosphere monitoring

Zoned electrical equipment

No naked flames or hot work

Ventilation of hazardous areas

Active BOG management

Isolation philosophy

Work planning and management

Atmosphere monitoring

LNG/Gas

SGMF
### Table B3: Impact of maintenance on the mitigation of consequences

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Barrier</th>
<th>Compromising impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold injury or fatality</td>
<td>PPE</td>
<td>Wrong PPE issued</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PPE not worn correctly</td>
</tr>
<tr>
<td></td>
<td>Training and competence</td>
<td>Poor behaviour – for example, touching equipment or piping to test whether it is cold</td>
</tr>
<tr>
<td></td>
<td>Working procedure</td>
<td>Prolonged exposure to a cold space/atmosphere</td>
</tr>
<tr>
<td></td>
<td>Equipment/piping insulation</td>
<td>Removal of wrong or too much cryogenic insulation</td>
</tr>
<tr>
<td>Cold embrittlement</td>
<td>Suitable materials</td>
<td>Replacement of parts with lower, inappropriate specifications</td>
</tr>
<tr>
<td>Fire and/or explosion</td>
<td>No naked flames</td>
<td>Hot work taking place</td>
</tr>
<tr>
<td></td>
<td>Atmospheric monitoring</td>
<td>Removal or compromising of gas detection system</td>
</tr>
<tr>
<td></td>
<td>Ventilation</td>
<td>Ventilation switched off or flow partially compromised</td>
</tr>
<tr>
<td></td>
<td>Zoned electrical equipment</td>
<td>Non-zoned sparking electrical tools/lighting/ventilation fans</td>
</tr>
<tr>
<td></td>
<td>Working procedure</td>
<td>Wrong working methods leading to build-up of static</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-sparking working practices ignored – for example, sparking tools, lighting and ventilation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Access control ineffective</td>
</tr>
</tbody>
</table>
### Table B3: Impact of maintenance on the mitigation of consequences (continued)

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Barrier</th>
<th>Compromising impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire and/or explosion</td>
<td>Training and competence</td>
<td>Inappropriate behaviour – for example, mobile phones and smoking</td>
</tr>
<tr>
<td></td>
<td>Protective system</td>
<td>Fails to operate because under repair, non-powered or alarm doesn’t trigger – for example, fire pump</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flame screens/fire extinguishers removed for ease of access</td>
</tr>
<tr>
<td>Greenhouse gas release</td>
<td>Active BOG Management</td>
<td>Consumers off line for maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Services required to run consumers (for example cooling water) not available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poor work planning, scheduling, procurement and/or management</td>
</tr>
<tr>
<td></td>
<td>Poor work planning,</td>
<td>Work delays and failure of gas pressure management plan</td>
</tr>
<tr>
<td></td>
<td>scheduling, procurement and/</td>
<td></td>
</tr>
<tr>
<td></td>
<td>or management</td>
<td></td>
</tr>
<tr>
<td>Asphyxiation</td>
<td>Atmosphere monitoring</td>
<td>Failure to take appropriate atmosphere measurements</td>
</tr>
<tr>
<td></td>
<td>Working procedure</td>
<td>Working without a rescue line and watchman</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolations not effective allowing gas/N2 to leak into space</td>
</tr>
</tbody>
</table>
Worked Example 1 – Hot Work During a Gas Escape
A vessel enters a dry dock with LNG/gas fuel onboard. The maintenance, for whatever reason, overruns meaning that the pressure inside the LNG tank increases to the point where the relief valves lift. The principal barrier – the “gas-management plan” in Figure B4 – has failed and a threat has occurred, resulting in a hazard: a gas escape.

The remaining mitigation for this threat is the vent mast system. The barrier works, so the integrity of the fuel tank is protected and the gas escape is limited to a specific point on the vessel. However, there is a consequence, a greenhouse gas escape that will harm the environment. There may be a second consequence as the gas escape is potentially flammable and may ignite.

From Figure B5, if hot work is occurring on or near the vent mast, one of the barriers to ignition has been overridden by a maintenance activity, making ignition more likely. In the event of the active hazard (venting of gas), it would be wise to stop work immediately and prohibit further hot work for the duration of the hazard.

Worked Example 2 – Event Tree Analysis During Gas-Detector Cable Re-routing
The instrument cables from flammable-gas detectors in one area of the vessel are being re-routed to accommodate a new item of equipment. During this period the flammable gas system has been disabled.

A threat in Figure B4, disabling/impairment of the control system, has occurred. This is only a problem if a hazard occurs simultaneously. Portable flammable gas-detection monitors might be used as a temporary barrier to overcome the lack of a fixed system. To be effective, this might require an additional worker dedicated to constantly monitoring the portable detector AND having an agreed alarm system (such as a radio or air horn) AND the staff in the area being told what to do in the event of the new alarm. This temporary system is likely to be less reliable than the permanent equipment and may only be able to operate for a limited period of time.
Other mitigation options could also be used, such as removing all the gas/LNG from the area by depressurising and isolating gas/LNG pipework, by closing valves and purging it with nitrogen, OR increasing the ventilation rate to ensure that LFL is never reached OR stopping work (but not monitoring) and removing workers from the area until the new cabling is complete and confirmed effective by testing.

The use of AND and OR suggests the use of an event tree as a way of confirming effectiveness (that is, a high probability of positive outcomes) and therefore a lack of risk. An event tree analysis considers the responses to an initiating event (the hazard) and lays a path for assessing probabilities of the outcomes and overall system analysis, Figure B6.

The Event Tree is used to analyse the effects of functioning or failed systems, given that an event has occurred, or to identify all consequences of a system that have a probability of occurring after the initiating event.
Figure B6: Event tree

EVENT

Flammable gas detection system disabled

Gas free area or ship

Use a portable gas detector

Increase ventilation – effectiveness?

Stop work until repaired

POTENTIAL ACTIONS

Yes

Agree new alarm protocol

YES

All staff briefed on new alarm/escape system

Yes

No

NO

RESULT

No gas to potentially harm workforce

Working system effective, potential for harm reduced

Gas detected, alarm sounded, staff unclear of their actions

Gas detected but no way to alert workers – potential for harm

No effective gas detection – harm possible

LFL cannot be achieved, potential for harm reduced

Ventilation ineffective – harm still occurs if gas leaks

No workforce in area subject to potential harm
Worked Example 3 – Incident Report

A shipyard worker is tasked with modifying a service pipe (carrying a relatively inert fluid, perhaps nitrogen or a water-glycol mix) in the fuel preparation room to allow the insertion of a valve. The worker makes an error in identifying the correct pipe and instead cuts into a pipe containing natural gas, using a cutting torch. Fortunately, the worker escapes without injury but the consequences could have been much more serious. (This actually happened in Scandinavia.)

There are several processes that can help avoid errors like this. They include:

- a line walk with ship’s staff to identify correctly the piping concerned
- verifying the line against Process & Instrumentation Diagrams (P&IDs) and isometrics drawings
- isolating all the hazardous pipework (via the permit-to-work system) in the work area so that any release is minimised
- gas freeing all or part of vessel
Appendix C: Hazardous Areas

Area classification has been developed to categorise explosive gas atmospheres, ensuring the correct selection and installation of equipment, known to operate safely in a particular environment. Categories are subdivided to take into account the properties of the flammable materials present. The zone definitions take no account of the consequences of a release.

Hazardous areas generally refer to gas not LNG. There is limited information available on how to define hazardous zones for LNG. Energy Institute standard IP15 provides guidance, as does – to a limited extent – US standard NFPA59A.

Hazardous areas are categorised into the following zones:

<table>
<thead>
<tr>
<th>Event</th>
<th>European &amp; IGF Code</th>
<th>US (NFPA 70)</th>
<th>Time guidance (not officially adopted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>An area in which an explosive gas atmosphere is present continuously or for long periods</td>
<td>Zone 0</td>
<td>Class 1 Division 1</td>
<td>Explosive atmosphere for more than 1,000 hours per year</td>
</tr>
<tr>
<td>An area in which an explosive gas atmosphere is likely to occur in normal operation</td>
<td>Zone 1</td>
<td>Class 1 Division 1</td>
<td>Explosive atmosphere for more than 10, but less than 1,000 hours, per year</td>
</tr>
<tr>
<td>An area in which an explosive gas atmosphere is not likely to occur in normal operation and, if it occurs, will only exist for a short time</td>
<td>Zone 2</td>
<td>Class 1 Division 2</td>
<td>Explosive atmosphere for less than 10 hours per year, but still sufficiently likely to require controls over ignition sources</td>
</tr>
<tr>
<td>An area in which an explosive gas atmosphere will not occur in normal operation</td>
<td>Non-hazardous or safe area</td>
<td></td>
<td>No explosive atmosphere present</td>
</tr>
</tbody>
</table>

If intrinsically-safe electrical equipment is to be used, additional data is required – based on the combustion properties of the gas involved – to confirm the equipment is intrinsically safe.
Table C2: Gas groups for hazardous area classification

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Gas group</th>
<th>Temperature designation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Europe/ International</td>
<td>North America</td>
</tr>
<tr>
<td>LNG/CNG</td>
<td>IIA (methane)</td>
<td>D (methane)</td>
</tr>
<tr>
<td>Ethane</td>
<td>IIA</td>
<td>T1 (above 450°C)</td>
</tr>
<tr>
<td>LPG</td>
<td>IIA (propane &amp; butane)</td>
<td>T1 – propane (above 450°C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T2 – butane (above 300°C)</td>
</tr>
</tbody>
</table>

All gas-fuelled ships will follow the definitions in the IGF Code, which are identical to definitions for onshore plant (such as shipyard equipment) in Europe. The US defines the zones slightly differently. Most other national jurisdictions follow either the US or European systems.

The hazardous zones must be defined for all components of the low-flash point fuel system, including the bunkering system, fuel storage, supply and distribution, and end use. This only needs to be performed once as part of the construction process unless changes are made to the equipment, in which case the hazardous zone calculations need to be revised. The shipbuilder or modifier, on behalf of the owner, must use this information to determine the size and location of the hazardous zones.

Calculating distances for the hazardous zone is relatively straightforward as the calculation methods are defined by national/international standards. The standards vary by home location and type of use (onshore and shipping). Hazardous area calculations for shore-based equipment are defined by local or regional standards.

Maritime practice is covered by the various IMO codes, which are subsidiary parts of SOLAS. For IGF Code ships Section 12 of the code (see Table C3) has definitions of what a hazardous area is and specifically describes where these are located, what size they should be, and their impact on electrical equipment design (standard IEC 60092).
Where several hazardous areas exist they must be combined to produce a single hazardous zone – not considered in isolation. This hazardous zone exists in three dimensions and may extend beyond the low-flashpoint-fuelled ship.

Figure C2 shows the components of a gas-fuelled ship where gas or LNG vapour may be present.

*Figure C2: Hazardous zones on a gas-fuelled Offshore Support Vessel (OSV) (© Harvey Gulf International Marine)*

Section 12.5 of the IGF Code defines hazardous zones by location and the likelihood of the presence of a flammable atmosphere. These are shown in Table C3.
### Table C3: Hazardous areas (IGF Code)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 0</td>
<td>interiors of fuel tanks</td>
</tr>
<tr>
<td></td>
<td>pipes and equipment containing fuel</td>
</tr>
<tr>
<td></td>
<td>any pipework for pressure relief or other venting systems for fuel tanks</td>
</tr>
<tr>
<td>Zone 1</td>
<td>tank connection spaces, fuel storage hold spaces (fuel storage hold spaces for type C tanks are normally not considered as Zone 1) and inter-barrier spaces</td>
</tr>
<tr>
<td></td>
<td>fuel preparation room arranged with ventilation</td>
</tr>
<tr>
<td></td>
<td>areas on open deck, or semi-enclosed spaces on deck, within 3 m of any fuel tank outlet, gas or vapour outlet (such areas include, all areas within 3 m of fuel tank hatches, ullage openings or sounding pipes for fuel tanks located on open deck and gas vapour outlets) bunker manifold valve, other fuel valve, fuel pipe flange, fuel preparation room ventilation outlets and fuel tank openings for pressure release provided to permit the flow of small volumes of gas or vapour mixtures caused by thermal variation</td>
</tr>
<tr>
<td></td>
<td>areas on open deck or semi-enclosed spaces on deck, within 1.5 m of fuel preparation room entrances, fuel preparation room ventilation inlets and other openings into Zone 1 spaces</td>
</tr>
<tr>
<td></td>
<td>areas on the open deck within spillage coamings surrounding gas bunker manifold valves and 3 m beyond these, up to a height of 2.4 m above the deck</td>
</tr>
<tr>
<td></td>
<td>enclosed or semi-enclosed spaces in which pipes containing fuel are located – for example, ducts around fuel pipes, and semi-enclosed bunkering stations</td>
</tr>
<tr>
<td></td>
<td>the ESD-protected machinery space is considered a non-hazardous area during normal operation, but will require equipment certified as suitable for Zone 1 following detection of gas leakage</td>
</tr>
<tr>
<td></td>
<td>a space protected by an airlock is considered as a non-hazardous area during normal operation, but will require equipment certified as suitable for Zone 1 following loss of differential pressure between the protected space and the hazardous area</td>
</tr>
<tr>
<td></td>
<td>except for type C tanks, an area within 2.4 m of the outer surface of a fuel containment system where such surface is exposed to the weather</td>
</tr>
</tbody>
</table>
Table C3: Hazardous areas (IGF Code) (continued)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 2 IGF 12.5.3 Instrumentation and electrical apparatus installed within these areas should be of a type suitable for Zone 2</td>
<td>this zone includes, but is not limited to, areas within 1.5 m surrounding open or semi-enclosed spaces of Zone 1</td>
</tr>
<tr>
<td></td>
<td>space containing bolted hatch to tank connection space</td>
</tr>
</tbody>
</table>

Hazardous areas on open deck and other spaces not addressed above shall be decided based on a recognised standard such as IEC standard 60092-502, part 4.4.

Special precautions should be taken in hazardous zones to prevent ignition and thereby ensure the safety of workers and integrity of the vessel. These typically take four forms:

- at the design stage, there needs to be proper selection and installation of fixed equipment to be used safely in that environment, taking into account the properties of the flammable atmosphere that may be present. If possible, electrical equipment and wiring should not be installed in hazardous zones. However, if required, such equipment can meet the standard (IEC 60092-502) for operation in various ways, as shown in Table C4.

- during operation gases/vapours resulting from low-flashpoint fuels can leak from:
  - flanges and other connectors not properly connected and tightened
  - valve stems, glands and packings
  - pressure- and temperature-relief systems
  - pipework and equipment damaged by impact, vibration, stress and/or corrosion
  - areas of poor or incomplete welding on fuel or vapour pipework
• there should be proper and effective work control during maintenance activities to prevent new leak pathways being created.

• during maintenance activities, correct inspection and maintenance procedures should be applied to the installed equipment. There should also be control of the introduction of electrical and non-electrical sources of ignition (any portable equipment) required to perform the work. Gases/vapours resulting from low-flashpoint fuels can leak from all the design faults listed above, plus the following:
  * damage to a gas-containing system – for example, cutting into the wrong pipe or dropping a heavy and/or sharp object onto a flange, resulting in larger leaks
  * the opening of valves or removal of pipework, allowing gas to escape

**Table C4: Electrical equipment protection systems for hazardous areas**

<table>
<thead>
<tr>
<th>Protection method</th>
<th>Type of protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevent a flammable mixture from reaching an ignition source</td>
<td><strong>Ex</strong> <strong>m</strong> Encapsulation</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>p</strong> Pressurisation</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>nP</strong> Simple pressurisation</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>nR</strong> Restricted breathing</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>o</strong> Oil immersion</td>
</tr>
<tr>
<td>Prevent ignition from occurring</td>
<td><strong>Ex</strong> <strong>e</strong> Increased safety</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>nA</strong> Non-sparking</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>m</strong> Encapsulation</td>
</tr>
<tr>
<td>Prevent ignition from spreading</td>
<td><strong>Ex</strong> <strong>d</strong> Flameproof enclosure</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>q</strong> Powder filling</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>nC</strong> Enclosed break</td>
</tr>
<tr>
<td>Limit the ignition energy in a circuit</td>
<td><strong>Ex</strong> <strong>ia</strong> Intrinsic safety</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>ib</strong> Intrinsic safety</td>
</tr>
<tr>
<td></td>
<td><strong>Ex</strong> <strong>nL</strong> Energy limitation</td>
</tr>
<tr>
<td>Other</td>
<td><strong>Ex</strong> <strong>s</strong> Special protection</td>
</tr>
</tbody>
</table>
Appendix D: Management of Change

When a piece of equipment or a piping system is being designed, it generally goes through a verification process during which risk assessments and studies are reviewed by an independent person and the assumptions and calculations behind the design are checked. This verification process ensures the design is safe – meaning that it will operate as it is supposed to throughout its lifetime.

Design is not just about physical objects but must also incorporate the procedures – both operating and maintenance – that accompany them and the safety management and auditing systems that ultimately ensure their effectiveness. These too need to be independently reviewed.

When a process, system or major physical component is modified, often for very good reasons, the design and/or procedural changes need to be reviewed with the same vigour as the original design to ensure continued safety.

Management of change may also apply to organisational and managerial changes – for example, amendments to staffing or skill levels. Even small changes may need a change management process. Change management is a culture – a way of thinking – as well as a set of techniques that allow change to happen safely.

Management of change processes require a thorough review of the proposed change. This should be undertaken in a structured way, by a multidisciplinary team, to ensure that all aspects of the change and the risks/hazards that might result have been understood, suitably mitigated, and documented.

Techniques such as HAZOP and commissioning reviews are often used to examine the implications of the changes and to check that existing mitigations remain effective; if not, they may also need to be changed to reflect the new circumstances.

When complete, the change management process needs to be signed off by an appropriate person of suitable seniority. This managerial level may
need to change if the potential impacts of the change become greater.

Typical processes requiring a management of change process should be defined by the vessel owner but should include changes to the following items (points with particular emphasis for IGF ships are shown in **bold**):

- propulsion, steering and navigation
- cargo containment, handling and monitoring
- fuel storage, handling (bunkering and distribution), monitoring and control
- structural elements that may impact seaworthiness
- safety control systems (particularly fire and gas and emergency shut-down systems) and emergency management equipment (such as firefighting, spill response and life-saving)
- hazardous areas
- supervisory control systems and their software

Change means:

- new equipment (to do a new task)
- replacement of existing equipment (even if presumed to be a like-for-like replacement)
- modification of existing equipment
- modification and/or replacement of computer hardware
- modification to software (such as alarms, control parameters and interlocks)
- bypasses around equipment that is not in service
- disabling of alarms and trips for testing, calibration or maintenance
- modification, addition or removal of emergency equipment
- changes to pipe and equipment support
- changes to different chemicals or materials of construction (such as gaskets and piping)
• changes to the frequency or extent of maintenance and inspection activities
• changes to controlled documents, such as operating and maintenance manuals
• new procedures
• operations outside of current procedures
• applying new regulations to existing vessels after corporate, national and/or international rule changes
• change of manning levels or crew responsibilities
• transfer of Class or Flag

Key elements of a change process include the following:

• the change should be fully defined, particularly if it is just a replacement of like-for-like because some small details may have changed, with potentially unexpected results.
• is the change temporary or permanent? Will the system return to its original configuration once a replacement part is sourced or will the change be permanent? How long does it take for something to become permanent?
• what is an emergency change? Should this have a lower rigour than a temporary or permanent change?
• is this a physical change someone might see or a procedural one that corrects a near-miss or bad habits?
• how has the change been communicated? Do operating behaviours need to change? Is training required?
• has the change been properly documented so that the next crew/shift knows what has happened and, crucially, why?
**Flixborough, UK, 1974**

A chemical plant owned by Nypro UK making feed materials for nylon production was unable to produce the required amount of product when the price was high. One reactor was taken out of service after a leak but commercial pressures to continue production meant that parts of this process train continued to operate. To achieve this, a temporary pipe needed to be installed around the reactor while it was repaired. This pipe was not of the right design and failed two months after installation. The resulting gas cloud exploded – killing 28 people, injuring 86 and damaging 2,000 nearby properties.

ICI, a major UK chemical company with similar facilities, immediately reviewed how it controlled modifications of its plants, which resulted in “management of change processes” that have now been adopted worldwide in many industries.