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关于 IACS 发布 REC.146 的技术通告

1 背景

IGF 规则第 4.2 条要求使用低闪点燃料的船舶进行相关的风险分析，风险分析应符合“可接受”、“公认”及“形成主管机关满意的文件”，但未给出满足这三项要求的具体标准，即（1）什么样的风险评估是可接受的；（2）风险评估要到达什么样的公认程度；及（3）什么样的文件是令主管机关满意的。为此，国际船级社协会编写通过了关于满足 IGF 规则要求的风险评估的建议案 REC.146，并于 2016 年 8 月发布了该建议案。本建议案给出了通用的风险分析方法和流程，明确了满足上述三项要求的具体标准，提高了执行风险分析规定时的标准性和一致性。

2 技术要点

由于存在多种“可接受”和“公认”风险评估技术和记录风险评估文档的方法，REC.146 建议案并不旨在限定风险评估的具体技术或文档记录方法，而是描述了满足 IGF 规则的推荐做法和实例，并明确了风险评估的目的、范围、推荐方法、团队成员以及风险评估报告的要求。对于风险评估方法，本建议案主要描述了满足 IGF 规则要求的定性风险评估（QualRA），定性风险评估的内容主要包括：危险识别、后果分析、可能性分析、风险分析以及风险评估。

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附件：IACS REC.146 (Ver. Aug 2016)-中英文版

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Risk assessment as required by the IGF Code

1.1 General

To help eliminate or mitigate risks a risk assessment is required by the IGF Code[1]. In this regard it requires that the risk assessment is undertaken using acceptable and recognised techniques, and the risks and their mitigation are documented to the satisfaction of the Administration.

It is recognised that there are many acceptable and recognised techniques and means to document a risk assessment. As such, it is not the intent of this document to limit a risk assessment to a particular technique or means of documentation. This document does, however, describe recommended practice and examples to help satisfy the IGF Code.

1.2 Risk assessment - Objective

The objective or goal of the risk assessment, as noted in the IGF Code, is to help *"eliminate or mitigate any adverse effect to the persons on board, the environment or the ship"*[2]. That is, to eliminate or mitigate unwanted events related to the use of low-flashpoint fuels that could harm individuals, the environment or the ship.

1.3 Risk assessment - Scope

The IGF Code requires the risk assessment to cover the use of low-flashpoint fuel[3]. This is taken to mean assessment of the supply of such fuel to consumers and covers:

- equipment installed on board to receive, store, condition as necessary and transfer fuel to one or more engines, boilers or other fuel consumers;
  Such equipment includes manifolds, valves, pipes/lines, tanks, pumps/compressors, heat exchangers and process instrumentation from the bunker manifold(s) to delivery of fuel to the consumers.

- equipment to control the operation;
  For example, pressure and temperature regulators and monitors, flow controllers, signal processors and control panels.

- equipment to detect, alarm and initiate safety actions;
  For example, detectors to identify fuel releases and subsequent fires, and to initiate shutdown of the fuel supply to consumers.

- equipment to vent, contain or handle operations outside of that intended (i.e. outside of process norms);
  For example, vent lines, masts and valves, overflow tanks, secondary containment, and ventilation arrangements.

- fire-fighting appliances and arrangements to protect surfaces from fire, fuel contact and escalation of fire;
  For example, water sprays, water curtains and fire dampers.

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1. International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) - as adopted at MSC 95 (June 2015).
2. IGF Code (ref 1 of this document), Part A, Chapter 4.1.
3. IGF Code (ref 1 of this document), Part A, Chapter 4.2, Paragraph 4.2.1.

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- equipment to purge and inert fuel lines;
  For example, equipment to store and supply nitrogen for the purposes of purging/inerting bunker lines, and equipment used for the safe transfer/disposal of fuel.

- structures and constructions to house equipment;
  For example, fuel storage hold spaces, tank connection spaces and fuel preparation rooms.

In agreement with stakeholders (e.g. the Administration) the scope can exclude items that have been previously subjected to a risk assessment, provided there are no changes to 'context of use' and mitigation measures taken as a result of previous risk assessment are to be included. This can help reduce assessment time and effort.

The term 'context of use' (used above) refers to differences, such as differences in design or arrangement, installed location, mode of operation, use of surrounding spaces, and the number and type of persons exposed. For example, if an item is located on a cargo ship on-deck, it is a change to the 'context of use' if the same item is then installed below deck on a passenger ship. In addressing 'context of use' it is important to recognise that these 'differences' can significantly decrease or increase risk resulting in the need for fewer, more, changed or alternative means to eliminate or mitigate the risks.

With regards to liquefied natural gas (LNG), the IGF Code states that risk assessment "need only be conducted where explicitly required by paragraphs 5.10.5, 5.12.3, 6.4.1.1, 6.4.15.4.7.2, 8.3.1.1, 13.4.1, 13.7 and 15.8.1.10 as well as by paragraphs 4.4 and 6.8 of the annex". Hence, the IGF Code allows the scope of the risk assessment to be limited to these paragraphs. It is important to note that there are differences of opinion on the scope of risk assessment required by these paragraphs. Therefore, the views of stakeholders and approval by the Administration should be sought when finalising the scope of the risk assessment.

The risk assessment includes consideration of bunkering equipment installed on board but does not cover the bunkering operation of: ship arrival, approach and mooring, preparation, testing and connection, fuel transfer, and completion and disconnection. Bunkering of fuel is the subject of separate assessment as per ISO/TC18683 and reference should be made to appropriate and specific guidance.

The IGF Code requires that consideration is given to physical layout, operation and maintenance. Typically, the risks associated with maintenance are controlled by job specific risk assessments before the activity is undertaken. Therefore, consideration of maintenance is taken to mean high-level consideration of design and arrangements to facilitate a safe and appropriate working environment. This requires consideration of, for example, equipment isolation, ventilation of spaces, emergency evacuation, heating and lighting, and access to equipment. The purpose of this is to minimise the likelihood of unwanted events resulting in harm during maintenance. In addition, the purpose is to minimise the likelihood of unwanted events after maintenance, as a result of deficient work where a contributory cause was 'a poor working environment'.

The assessment should also appreciate potential systems integration issues such as equipment control and connection compatibility. This is particularly important where a number of stakeholders are involved in separate elements of design, supply, construction and installation.

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4. IGF Code (ref 1 of this document), Part A-1, Chapter 4.2, Paragraph 4.2.2.

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Occupational risks can be excluded from the risk assessment. They are an important safety consideration and are expected to be covered by the safety management system of the ship.

The scope should obviously cover the design and arrangement as installed on board. Therefore, where the risk assessment is undertaken prior to finalising the design, it may require revision to ensure that the risks remain ‘mitigated as necessary’.

The IGF Code makes no reference to periodic update of the risk assessment. This should be undertaken where changes to the design/arrangement and/or its operation have been made, and in response to changes in performance of equipment and controls. This helps ensure the risks are ‘mitigated as necessary’ through-out the life of the fuel system.

The final scope of the risk assessment should be agreed with appropriate stakeholders (e.g. the Administration) and guided by applicable classification rules and the IGF Code.

1.4 Risk assessment - Approach

IMO has published guidance on formal safety assessment (FSA) and this provides useful information on risk assessment approaches and criteria[5]. The purpose of the guidance is to help evaluate new regulations on maritime safety and protection of the environment. In this regard, assessment is focused on risk quantification and cost benefit analysis to inform decision-making. As such, it is a useful reference to IMO’s views on risk assessment and criteria. However, the IGF Code does not require a quantitative measure of risk to people, the environment or assets from the use of fuel. The risk assessment is simply required to provide information to help determine if further measures are needed to ‘eliminate’ risks or to ensure they are ‘mitigated as necessary’. Therefore, a qualitative or semi-quantitative approach to the risk assessment is appropriate (i.e. Qualitative Risk Assessment, QualRA[6]). That is not to say that a fully quantitative approach is inappropriate or that circumstances might not favour its use (i.e. Quantitative Risk Assessment, QRA). What is important is that the risk assessment is of sufficient depth to help demonstrate that risks have been ‘eliminated’ or ‘mitigated as necessary’.

As a minimum, the risk assessment should detail:

A. how the low-flashpoint fuel could potentially cause harm – Hazard identification;
That is, systematic identification of unwanted events that could result in, for example, major injuries or fatality, damage to the environment, and/or loss of structural strength or integrity of the ship.

B. the potential severity of harm – Consequence analysis;
That is, the potential severity of harm (i.e. consequences) expressed in terms of, for example, major injuries, single and multiple fatalities, adverse environmental impact, and structural/ship damage sufficient to compromise safe operations.

C. the likelihood of harm – Likelihood analysis;
That is, the probability or frequency with which harm might occur.

D. a measure of risk – Risk analysis;
That is, a combination of consequence (B) and likelihood (C).

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5. Revised Guidelines for formal safety assessment for use in the IMO rule-making process. MSC-MEPC.2/Circ.12, 8th July 2013.
6. Where some form of quantification occurs, then the approach is semi-quantitative. However, such approaches are often referred to as qualitative and this term is used throughout this document.

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E. judgements on risk acceptance – Risk assessment.
The measure of risk (D) should be compared against criteria to judge if the risk has been 'mitigated as necessary'.

Acceptable and recognised techniques to address the requirements noted above (i.e. A-D) are described in, for example, ISO 31010[7], ISO 17776[8], ISO 16901[9], NORSOK Z-013[10], CPR 12E[11], and publications by CCPS[12] and HSE[13], etc.

The following sub-section, A1.4.1, outlines an approach to meeting the above requirements.

1.4.1 An approach to satisfying the IGF Code requirements - Qualitative Risk Assessment (QualRA)

A. Hazard identification

1. Divide the fuel system into discrete parts with respects to equipment function and location.
This promotes systematic consideration of each part of the system and helps identify specific causes of unwanted events related to a particular item, activity or section. A typical division of the system might be, for example: (a) the bunker station and fuel lines to the storage tank; (b) the fuel storage hold space; (c) the tank connection space; (d) the fuel preparation room; and (e) the fuel lines and valves 'regulating' fuel delivery to the engine.

2. Develop a set of guidewords/phrases and example causes that could result in unwanted events (e.g. a release of fuel or fuel system failure resulting in loss of power).
The guidewords/phrases and example causes are used as prompts. A typical, but not exhaustive list of prompts is given in Appendix 1.

3. By reference to design and arrangement information, location plans, process flow diagrams, mitigation measures and planned emergency actions use the prompts to identify potential causes of unwanted events (e.g. fuel releases and loss of power).
The prompts are used to stimulate discussion and ideas within a workshop led by a facilitator and attended by subject matter experts (SMEs).

4. Record the potential causes of unwanted events and mitigation measures
An example of a record sheet or worksheet is given in Appendix 2. This worksheet is also used to record steps B to E below, and forms part of the overall documentation of the risk assessment.

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7. Risk management: Risk assessment techniques. IEC/ISO 31010:2009.
8. Petroleum and natural gas industries - Offshore production installations - Guidelines on tools and techniques for hazard identification and risk assessment. EN ISO 17776:2002.
9. Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface. ISO/TS 16901:2015.
10. Risk and emergency preparedness assessment. NORSOK Standard Z-013, Edition 3, October 2010.
11. Methods for determining and processing probabilities. CPR 12E, 1997/2005.
12. e.g. Guidelines for chemical process quantitative risk analysis. Centre for Chemical Process Safety, American Institute of Chemical Engineers, Second Edition, 2000.
13. e.g. Marine risk assessment. Health & Safety Executive, 2001.

B. Consequence analysis

5. For each identified cause, estimate the potential consequences in terms of, for example, major injuries, single and multiple fatalities, adverse environmental impact and damage sufficient to compromise safe operations.
The potential consequences can be estimated by the SMEs using judgement and reference to: (a) the fuel's properties/hazards; (b) the release location; (c) dispersion/leak pathways; (d) location and 'strength' of ignition sources; (e) proximity of vulnerable receptors; (f) generic or (if commissioned) specific fire and explosion modelling; and (f) expected effectiveness of existing/planned mitigation measures. The properties and hazards of liquefied natural gas (LNG) noted in (a) are summarised in Appendix 3.

6. Categorise the consequence estimates.
The consequences can be categorised by the SMEs to provide an indication of severity. For example, categories for harm to persons can distinguish between major injury, single fatality and multiple fatalities. Example consequence categories are given in Appendix 4.

C. Likelihood analysis

7. Estimate the annual likelihood of occurrence of 'cause and consequence'.
Likelihood can be estimated by the SMEs (or a suitably qualified individual) for each 'cause-consequence' pair or a grouping of causes with the same consequence. The estimation can be informed by reference to accident and near-miss reports, accident and equipment release data, analogy to accidents in similar or other industries and consideration of the reliability and effectiveness of mitigation measures. It is not always apparent if the likelihood of a 'cause-consequence' combination is credible (i.e. reasonably foreseeable). As a guide, an unwanted event may be considered credible if: (a) it has happened before and it could happen again; (b) it has not happened but is considered possible with an annual likelihood of 1 in a million or more; and (c) it is planned for, that is, emergency actions cover such a situation or maintenance is undertaken to prevent it. A guide to the likelihood of releases relevant to LNG equipment and operations is given in Appendix 5.

8. Categorise the likelihood estimates.
Likelihood can be categorised by the SMEs (or a suitably qualified individual) to provide an indication of accident/incident occurrence or other unwanted event occurrence. Example likelihood categories are given in Appendix 4.

D. Risk analysis

9. Estimate the risk.
Risk can be estimated by the SMEs (or a suitably qualified individual) by combining the consequence and likelihood categories to provide a risk rating. For example, if a 'cause-consequence' pair is categorised as, say 'A', and associated 'likelihood' as, say '1', then the risk rating is 'A1'. An example of a risk rating scheme is given in Appendix 4.

E. Risk assessment

10. Judge if the risk has been 'mitigated as necessary'.
The estimated risk can be compared against risk criteria embedded within a risk matrix. The matrix shows the risk rating (with respects to consequence and likelihood) and the criteria illustrate whether the risk has been 'mitigated as necessary'. An example of a risk rating scheme and its associated risk criteria are given in Appendix 4.

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With respects to D and E above, it is important to note that there are no universally agreed risk rating schemes or risk criteria: there are differences between governments, regulators and organisations. Therefore, prior to the commencement of the risk assessment, risk rating/criteria should be agreed with appropriate stakeholders (e.g. the Administration).

It should also be recognised that the risk rating of individual or grouped 'cause-consequence' pairs does not provide an indication of the collective (overall) risk from all potential 'cause-consequence' pairs. If the overall risk level is required then this can be determined using QRA.

Practically, the risk rating is an indication that additional or alternative mitigation measures:

- must be provided; or
- must be considered and implemented if practical and cost effective; or
- need not be considered further, beyond accepted good practice of reducing risk where practicable.

In each of the steps above many assumptions are made and there is uncertainty. Therefore, it is good practice for SMEs to list assumptions and 'test' the sensitivity of results to changes in any of these steps. For example, a change to an assigned consequence or likelihood category could alter the risk rating and the judgement on whether a risk is 'mitigated as necessary'.

1.4.1.1 Mitigated as necessary

The phrase 'mitigated as necessary' is used in the IGF Code and is akin to the phrase 'As Low As Reasonably Practicable', commonly referred to as ALARP. Essentially, a risk is considered ALARP if all reasonably practicable mitigation measures have been implemented. This means that additional or alternative measures have been identified and implemented unless they are demonstrated as impractical or the cost of implementation is disproportionate to the reduction in risk. This concept of ALARP is established practice in many industries and recognised as best practice by IMO[14].

Where 'mitigated as necessary' is not proven then the SMEs should consider additional and/or alternative mitigation measures[15] and re-evaluate the risk. **The risk cannot be 'accepted' until 'mitigated as necessary' is achieved**. In this regard, additional study can be undertaken to help the SMEs decide if existing, additional or alternative measures can provide 'mitigated as necessary'.

14. Revised Guidelines for formal safety assessment for use in the IMO rule-making process. MSC-MEPC.2/Circ.12, 8th July 2013.

15. Within the IGF Code, measures to reduce likelihood and measures to reduce consequences are both understood to be mitigation measures (i.e. they mitigate the risk). To align with the IGF Code this understanding is maintained within this document. It is recognised that in many other industries it is common to use the terms 'prevention measures' and 'mitigation measures', where the former reduces likelihood and the latter reduces consequences. Prevention and mitigation measures are often referred to as 'safeguards' or 'barriers'.

When considering mitigation measures the following **hierarchy of mitigation** is considered best practice:

- firstly, measures to prevent an unwanted event;
  That is, to ensure the unwanted event cannot occur or its likelihood of occurrence is greatly reduced;

- secondly, measures to protect against harm given an unwanted event.
  That is, to reduce the consequences after the unwanted event has occurred.

In addition, when considering mitigation measures it is good practice to consider **engineering solutions in preference to procedural controls**. This helps promote an inherently safer design. Furthermore, it is good practice to consider **passive measures in preference to active measures**. For example, a passive measure is one where no manual or automated action is required for it to function on demand and as intended. Whereas, an active measure requires some means of activation for it to operate. Both passive and active measures may be required to demonstrate that the risk has been mitigated as necessary. Examples of mitigation measures are listed in Appendix 6.

To help judge if mitigation measures are effective it can be useful to illustrate or map the pathway from ‘cause’ to ‘consequence’ and review the effectiveness of the mitigation measures. An example of such mapping and review is given in Appendix 7.

Whether a single mitigation measure or a collection of mitigation measures is practical and cost-effective is in some respects relative to the resources and skills available. If the SMEs cannot decide then the use of cost benefit analysis can be helpful. In any case, a documented justification for not implementing a mitigation measure should be made where SMEs judge the measure to be practical and cost-effective.

1.5 Risk assessment - Team

The team conducting the risk assessment should comprise of subject matter experts (SMEs) who are, collectively, suitably qualified and experienced. For the QualRA noted above, this means the workshop team includes individuals who are degree qualified and/or chartered/professional engineers, have operational ship experience and are experienced in risk assessment. Such qualifications and experience should be in relevant disciplines to cover engineering design and safe use of the fuel.

It is unlikely that one SME can satisfy the above team requirements. In any case, to ensure investigative discussion, generation of ideas, challenge and coverage of, for example, mechanical, process, electrical and operational aspects, a typical number of SMEs might be four to eight.

In addition to the SMEs, the team should be led by a facilitator (also referred to as the chair or chairman). The facilitator should be impartial with no vested interests in the fuel system, and experienced in leading such risk assessments. The facilitator may be supported by a scribe (also referred to as a secretary) to aid reporting.

The time expended by the team depends upon the agreed scope and the designs’ ‘complexity’. For example, a QualRA workshop for a new design might require two or three working days, whereas, a minor variation to a previously assessed and approved design might require only half a day.

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1.6 Risk assessment - Reporting

1.6.1 Main report

A written report documenting the risk assessment should be produced. This needs to be sufficiently detailed to support results, conclusions, recommendations and any actions taken. This is because the assessment will inform important design and operational decisions. Furthermore, the report is a record in helping to demonstrate 'mitigated as necessary'. A report only consisting of a completed worksheet is insufficient.

The specific contents of the report and its structure are dependent upon design and assessment specifics, and reporting preferences. However, for a QualRA, the report should provide:

- an overview of the design and arrangement;
  This is a simple explanation of the design and arrangement with respects to its intended operation and process conditions. Technical appendices should include process flow diagrams, general arrangement plans and all information used during the assessment. Where this is too cumbersome to include in the report in full, reference to this material is sufficient provided it remains accessible.

- an explanation of the risk assessment process;
  This is a description of the risk assessment method and includes how the design was divided into parts for assessment, how hazard identification was undertaken, and the selection of consequence and likelihood categories and risk criteria.

- information on the relevant qualifications and expertise of the team;
  This can be a table listing the names, job titles, relevant qualifications, expertise and experience of all team members (including the facilitator and scribe). It is not sufficient to simply list names and job titles.

- the time taken to complete the assessment and whether SMEs were present to provide their expert input;
  For a workshop, this can be a table listing the schedule/duration and attendance of each SME (i.e. full-time or part-time, and if part-time the 'parts' for which the person was absent). The purpose of this is to indicate if sufficient time was taken to assess the design/arrangement, and to highlight any SME absences that could be detrimental to results, conclusions and actions. For any SME absences, a note should be made by the facilitator as to whether this impacted adversely upon the assumptions and judgements made.

- risk results and conclusions;
  This is a listing or discussion of the results and a judgement on whether or not the risk has been 'mitigated as necessary'.

- recommendations and actions.
  This can include requests for modelling and analysis (e.g. gas dispersion or thermal radiation extent, etc.) and will most likely include additional and alternative mitigation measures to be investigated and/or implemented, who is responsible for these and, if known, an expected completion date. It is important that these recommendations and actions are suitably documented because they are likely to be used to plan a response and monitor progress until the recommendations/actions have been addressed.

An example report contents is given in Appendix 8.

1.6.2 Terms of reference (ToR)

Prior to the workshop it is good practice for the facilitator to issue relevant information to the team. This is sometimes referred to as a terms of reference (ToR). This helps the team familiarise with the design and intended approach before the workshop. It also provides time for clarifications and agreement with the proposed consequence and likelihood categories and risk criteria. Importantly, it provides time to confirm the suitability of the proposed schedule and team. The ToR can form an appendix to the main report.

Typically, a ToR includes:

- objectives and scope of the assessment;
  This is to ensure all team members understand the objective and what equipment and operations are to be covered in the assessment.

- technical description of the proposed design and arrangements;
  This can include copies of process flow diagrams (PFDs) or schematics detailing process conditions of equipment and pipework, and a scaled layout drawing illustrating equipment and pipework arrangements, size and location.

- overview of the potential consequences of a fuel release;
  For LNG, this could refer to Appendix 3 of this document.

- technique to be used;
  This includes proposed consequence and likelihood categories and risk criteria.

- intended workshop schedule;
  This highlights the time to be given to the workshop and when SME input is required.

- team details.
  This includes the name and job title, relevant qualifications, expertise and experience of each SME and team member/workshop attendee.

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Appendix 1
Prompts - guidewords and phrases

Example prompts for use in QualRA

Failure of fuel containing equipment* – a hole/crack leading to release of fuel	
Wear and tear	*vibration, loading, cycling, prolonged use*
Erosion	*fuel contaminants, high stream velocity, prolonged use*
Stress and strain	*vibration, loading, cycling, ship movement, prolonged use*
Fatigue	*vibration, loading, cycling, ship movement, prolonged use*
Corrosion	*exposure to weather, exposure to sea water, humidity, loss of dry air supply, contact with corrosive materials*
Collision	*ship collides with another vessel, ship hits rocks, ship strikes the harbour wall or jetty*
Grounding	*ship runs aground*
Impact	*dropped object (e.g. during maintenance or cargo loading), collapse of supporting structure, maloperation during loading/maintenance*
Fire	*ignition of flammable materials, fire in adjacent spaces/areas*
** plus equipment containing gases or other substances that could release into spaces resulting in harm (e.g. asphyxiation, burns)*	
Failure of process control – operation outside of design conditions leading to subsequent release of fuel	
Temperature high	*loss of insulation, instrument failure, software failure, actuator failure, maloperation by operator, external fire, exposure to extreme weather, decomposition*
Temperature low	*loss of heating medium circulation, heating medium contamination, instrument failure, software failure, actuator failure, maloperation by operator, exposure to extreme weather*
Pressure high	*maloperation by operator (e.g. closed valve), loss of utilities (e.g. instrument air), external fire, loss of power supply, rollover, excess generation of boil-off gas, actuator failure*
Pressure low (vacuum)	*maloperation by operator, loss of utilities (e.g. instrument air), loss of power supply (electricity), actuator failure*
Flow high	*instrument failure, software failure, maloperation by operator, actuator failure, exposure to extreme sea conditions*
Flow low	*instrument failure, software failure, maloperation by operator, actuator failure, exposure to extreme sea conditions*
Flow reversed	*instrument failure, software failure, maloperation by operator (e.g. closed valve), exposure to extreme sea conditions*
No Flow	*instrument failure, software failure, maloperation by operator (e.g. closed valve), actuator failure*
Level high	*instrument failure, software failure, maloperation by operator, actuator failure, exposure to extreme sea conditions*
Level low	*instrument failure, software failure, maloperation by operator, actuator failure, exposure to extreme sea conditions*
Fuel left in pipe/line	*maloperation by operator, closed valves, no inert/purge supply, limited inert/purge supply*
No fuel in pipe/line	*instrument failure, software failure, maloperation by operator, closed valves*
Loss of power	*loss of electrical signals, blackout, loss of instrument air, loss of hydraulic fluid*

Note: Poor manufacturing, installation and commissioning of equipment can increase the likelihood and/or consequences of fuel releases. If these aspects are not covered and controlled by, for example, class rules, then they should be included in the risk assessment. The assessment should cover intended operation, shutdown and start-up.

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Appendix 2
Record sheet / Worksheet

Worksheet Example

Worksheet for [project title]											
Part or Section [title]											
						Category & Rating					
Item / Activity	Guideword / Phrase	Causes (accident / incident)	Consequences	Mitigation (existing safeguards)	Additional / Alternative Mitigation (safeguards)	Consequence	Likelihood	Risk	Mitigated as necessary	Recommendations Comments / Actions	Action by / date

Note: The worksheet can be used to record risk ratings before and after consideration of additional/alternative safeguards by using one row for ‘existing safeguards’ and one row for ‘additional/alternative safeguards’. If preferred, the ‘Additional/Alternative Mitigation (safeguards)’ column can be moved after the ‘Category & Rating’ columns followed by additional ‘Category & Rating’ columns.

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Appendix 3
Properties & hazards of liquefied natural gas

3.1 LNG Properties

Liquefied natural gas (LNG) is a cryogenic liquid. It consists of methane with small amounts of ethane, propane and inert nitrogen. When used as a fuel, typically 94% or more is methane. Stored at ambient or near ambient pressure, its temperature approximates minus 162 deg.C and its specific gravity is about 0.42. Hence, if released onto the sea LNG floats (and can rapidly ‘boil’ – refer to 3.2.7). When stored at pressures of up to 10 bar the temperature typically remains below minus 130 deg.C with a specific gravity of approximately 0.4.

Released into atmospheric conditions, LNG rapidly boils forming a colourless, odourless and non-toxic gas. Although colourless, due to its very low temperature, water vapour in the air condenses forming a visible mist or cloud. The cold gas is initially heavier than air and it remains negatively buoyant until its temperature rises to about minus 100 deg.C. At this stage the gas becomes lighter than air, and in an open environment it is thought that this coincides with a gas concentration of less than 5%. At this temperature and concentration the gas is still within the visible cloud. As the gas continues to warm to ambient conditions its volume is approximately 600 times that of the liquid with a relative vapour density of about 0.55, and so the gas is much lighter than air (air = 1).

As the gas disperses, its concentration reduces. At a concentration in air of between 5% and 15% the mix is flammable and can ignite in the presence of ignition sources or in contact with hot sources at or above a temperature of approximately 595 deg.C (referred to as the auto-ignition temperature). Once below a concentration of 5% the mix is no longer flammable and cannot be ignited (and this is the case if the concentration remains above 15%). The 15% and 5% concentrations of LNG in air are commonly known as the upper and lower flammability limits, respectively. More recently, the limits are referred to as the upper and lower explosion limits, although ignition may not necessarily result in explosion.

3.2 LNG Hazards

3.2.1 Cryogenic burns

Owing to its very low liquid temperature, in contact with the skin LNG causes burns. In addition, breathing the cold gas as it ‘boils’ can damage the lungs. The severity of burns and lung damage is directly related to the surface area contacted by the liquid/gas and duration of exposure.

3.2.2 Low temperature embrittlement

In contact with low temperature LNG, many materials lose ductility and become brittle. This includes carbon and low alloy steels typically used in ship structures and decking. Such low temperature embrittlement can result in material fracture, such that existing stresses in the contacted material cause cracking and failure even without additional impact, pressure or use. For LNG duty, materials resistant to low temperature embrittlement are used. These materials include stainless steel, aluminium, and alloy steels with a high-nickel content.

No. 146 (cont)

3.2.3 Asphyxiation

LNG is non-toxic and is not a known carcinogen. However, as it boils to gas it can cause asphyxiation as it displaces and then mixes with the surrounding air. The likelihood of asphyxiation is related to the concentration of gas in air and duration of exposure.

3.2.4 Expansion and pressure

Released into the atmosphere LNG will rapidly boil with the volume of gas produced being hundreds of times that of the liquid (approximately 600 times at ambient conditions). Hence, if confined and unrelieved, the pressure will increase and this can damage surrounding structures and equipment.

3.2.5 Fire

3.2.5.1 Pool fire

A 'small' release of LNG will rapidly boil and 'flash' to gas (i.e. evaporate). However, given a 'large' and sudden release, a cold pool of LNG will form with gas boiling from the pool and mixing and dispersing with the surrounding air. If this mix is within the flammable range (i.e. 5% to 15% with air) and contacts an ignition source or a heated surface above the auto-ignition temperature (595 deg.C) it will ignite and the resultant flame will 'travel back' to the pool resulting in a pool fire.

3.2.5.2 Jet fire

If stored under pressure then a release of LNG may discharge as a jet of liquid, entraining, vapourising and mixing with air. If the mix disperses and reaches an ignition source or a heated surface (above the auto-ignition temperature) whilst in the flammable range it will ignite. The resultant flame will 'travel back' and may result in a pressurised jet fire from the release source. Similarly, where contained LNG has been heated to form gas, a pressurised release of this gas could ignite and result in a jet fire.

3.2.5.3 Flash fire

Release of LNG to atmosphere and ignition within a few tens of seconds is likely to result in a pool fire or jet fire (as noted above) with no damaging overpressure. This is because the flammable part of the cloud is likely to be relatively small and close to the release point upon ignition. However, if ignition is delayed, the gas cloud will be larger and may have travelled further from the release point. Ignition will then result in a flash fire as the flammable part of the cloud is rapidly consumed within a few seconds. This ignition is likely to be violent and audible, and is often mistaken for an explosion, although there is little appreciable overpressure.

3.2.5.4 Thermal radiation from a pool fire, jet fire and flash fire

Harm to people and damage to structures and equipment from fire is dependent upon the size of the fire, distance from the fire, and exposure duration. Within a metre of the fire, thermal radiation may approximate 170 kW/m^2 but this rapidly falls with distance from the fire.

No. 146 (cont)

As a rough guide:

- 6 kW/m^2 or more and escape routes are impaired and persons only have a few minutes or less to avoid injury or fatality[16];
- 35 kW/m^2 results in immediate fatality[16];
- 37.5 kW/m^2 has long been considered as the onset of damage to industrial equipment and structures exposed to a steady state fire[17];
- industrial equipment and structures within a flash fire are unlikely to be significantly damaged; and
- persons within a pool, jet or flash fire are likely to be fatally injured.

An LNG fire on a ship could result in fatalities and damage to equipment and structures (including the hull).

3.2.6 Explosion

Release of LNG to atmosphere and delayed ignition of the resultant flammable cloud beyond a few tens of seconds can result in an explosion. This is because the cloud may have dispersed in and around equipment and structures causing a degree of confinement and increased surface area over which to increase flame speed as it travels (i.e. burns) through the flammable mixture. The resultant overpressure may be sufficient to harm individuals, and damage structures and equipment. Such an explosion is most likely to be a deflagration (rather than a detonation), categorised by high-speed subsonic combustion (i.e. the rate at which the flame travels through the flammable cloud).

3.2.6.1 Overpressure from an explosion

Harm to people and damage to structures and equipment from an explosion is dependent upon the magnitude of overpressure generated and the rate at which the overpressure is delivered (known as impulse). In addition, harm is often a result of falling or being thrown against hard surfaces or being struck by objects and debris as a result of the blast. As a rough guide:

- the probability of fatality from exposure to an explosion of 0.25 bar and 1 bar is about 1% and 50%, respectively[18];
- less than 0.25 bar could throw an individual against a hard surface resulting in injury or fatality[18]; and
- 0.3 bar is typically the limit of damage to structures and industrial equipment[18].

---

16. There are many quoted values from many sources and with inconsistencies. Thermal dose might be alternatively used. The values quoted here are based on: Health & Safety Executive, Indicative human vulnerability to the hazardous agents present offshore for application in risk assessment of major accidents, SPC/Tech/OSD/30, 2011, and supporting document: Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment, http://www.hse.gov.uk/foi/internalops/hid_circs/technical_osd/spc_tech_osd_30/spctecosd30.pdf
17. Risk Analysis of Six Potentially Hazardous Industrial Objects in the Rijnmond Area, A Pilot Study. (1982). D. Reidel Publishing Company, The Netherlands.
18. There are many quoted values from many sources and with inconsistencies. Impulse might be alternatively used. The values quoted here for fatality and damage are based on Ref 16 and Methods for the determination of possible damage to people and objects resulting from releases of hazardous materials, CPR 16E, Labour Inspectorate, The Netherlands.

No. 146 (cont)

An explosion of vapourised LNG on a ship could result in fatalities and damage to equipment and structures (including the hull).

3.2.7 Rapid phase transition

Upon release, LNG rapidly boils due to heat from the surrounds, be this from the air, water/sea, steel or ground. However, this rapid and sometimes violent boiling is not rapid phase transition (RPT); RPT is an explosive vaporisation of the liquid, that is, a near instantaneous transition from liquid to gas. This is a more violent event than rapid boiling and it can result in liquid ejection and damaging overpressure[19]. The phenomenon is well known in the steel industry, where accidental contact between molten metal and water can result in RPT.

3.2.8 Rollover

Slowly, stored refrigerated LNG evaporates (i.e. 'boils-off') as heat from the surrounds gradually 'leaks' into the tank. Essentially, liquid in contact with the wall of the tank warms, becomes less dense and rises to the top. This top-layer then begins to evaporate (i.e. boil-off) increasing the liquid layer's density. Liquid further away from the walls also warms but at a slower rate and because of this a less dense layer below the top layer forms. Owing to the hydrostatic head, the saturation condition of this layer changes and although it heats-up, it does not evaporate but remains in the liquid state and becomes 'superheated'. As the heating continues, the trapped layer's density reduces; this is an unstable state and when the density of this layer is similar to the top layer the two layers rapidly mix and the superheated lower layer vaporises. This rapid mixing and vaporisation is known as rollover and can cause damaging over-pressure and release of gas if not appropriately controlled.

The heating mechanism described above can result in a number of differing layers and is referred to as stratification. It is a phenomenon that is well known and is safely managed through venting, mixing and temperature control.

The above phenomenon is hastened by, or can directly occur when differing densities of LNG are bunkered.

3.3 References

The information and facts given in this appendix are well known and have been recorded in numerous papers and reports on LNG. However, original sources are not always readily available (or known) and so the information given in this section was cross-checked by reference to:

1. Chamberlain, G. (2006). Management of Large LNG Hazards. 23rd World Gas Conference, Amsterdam.

2. International Maritime Organization, Marine Safety Committee. (2007). FSA - Liquefied Natural Gas (LNG) Carriers, Details of the Formal Safety Assessment. MSC 83/INF.3.

3. Bull, D. and Strachan, D. (1992). Liquefied natural gas safety research.

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19. Chamberlain, G. (2006). Management of Large LNG Hazards. 23rd World Gas Conference, Amsterdam.

No.
146
(cont)

4. Sheats, D. & Capers, M. (1999). Density Stratification in LNG Storage. Cold Facts, 15/2.

5. Bashiri, A. & Fatehnejad, L. (2006). Modeling and Simulation of Rollover in LNG Storage Tanks. 23rd World Gas Conference, Amsterdam.

Reference can also be made to ISGOTT (International Safety Guide for Oil Tankers and Terminals) Publication (2009) - Report on the Effects of Fire on LNG Carrier Containment Systems.

No. 146 (cont)

Comparison of the Hazards of LNG and Fuel Oil

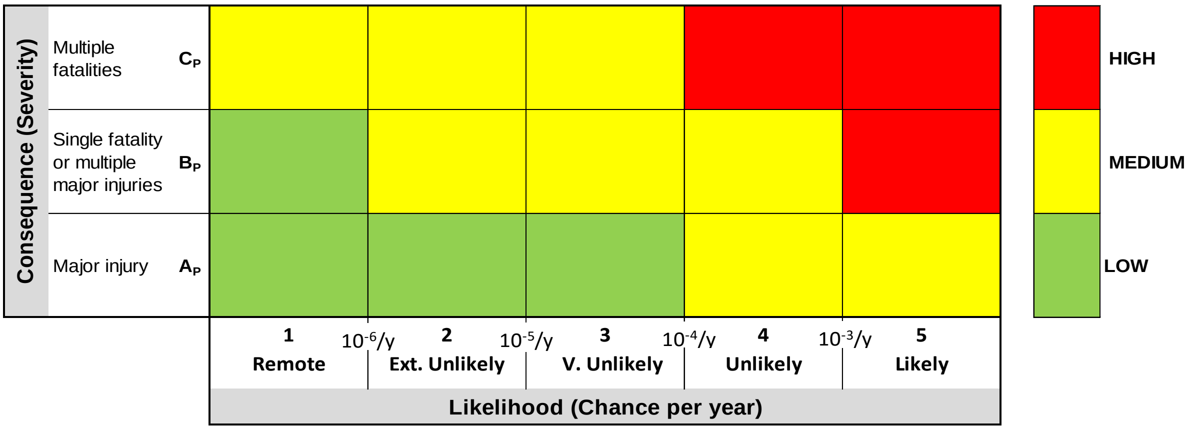
Hazards	LNG	Fuel Oil[1]
1. Cryogenic Burns Liquid contact with skin will cause burns and can result in fatality. Inhalation of gas can cause burns to the lungs and lead to fatal injury.	✓	X
2. Low Temperature Embrittlement Equipment/structures can fail on contact with liquid.	✓	X
3. Rapid Phase Transition (RPT) Released onto the sea a near instantaneous 'explosive' transition from liquid to gas can occur. This can result in structural damage to the hull.	✓	X
4. Gas Expansion A liquid pool rapidly boils, and as the gas warms and expands it requires a volume 600 times that of the liquid. This can result in equipment damage.	✓	X
5. Asphyxiation In a confined space, displacement and mixing of the gas in the air will reduce oxygen content and can cause asphyxiation.	✓	✓
6. Pool Fire Gas/vapour above the pool can ignite resulting in a pool fire. The intensity of the radiation can cause fatal injury and fail structure and critical equipment.	✓	✓
7. Flash Fire Gas/vapour can disperse away from the pool and ignite resulting in a flash fire. The short-duration and intense radiation can instigate secondary fires, and cause fatal injuries to those within the fire and to critical equipment. Most probably the fire will burn back to the pool and result in a pool fire.	✓	X[2]
8. Explosion Gas/vapour can disperse and collect in confined areas and ignite resulting in an explosion. The explosion can cause fatal injuries, instigate secondary fires, and fail structure and critical equipment. Most probably the explosion will burn back to the pool/gas source and result in a pool fire or jet fire.	✓	X[2]
9. Rollover Stored liquid can stratify, that is different layers can have different densities and temperatures. This can cause the layers to 'rollover' resulting in significant gas/vapour generation that must be contained. If released, this can result in flash fire or explosion.	✓	X
10. Boil-off Gas (BoG) LNG continually boils and must be re-liquefied or burnt-off. A release of BoG can ignite and result in a jet fire (given sufficient release pressure), flash fire or explosion.	✓	X

Note:
1. Fuel oil – heavy fuel oil (HFO) (ISO 8217).
2. If a fuel oil is 'sprayed' as an aerosol resulting in fine air-borne droplets, ignition can result in flash fire or explosion.

No. 146 (cont)

Appendix 4
Risk Matrix

Risk Matrix Example – persons on board



Consequence Category Examples

A_P Major injury - *long-term disability / health effect*
B_P Single fatality or multiple major injuries - *one death or multiple individuals suffering long-term disability / health effects*
C_P Multiple fatalities - *two or more deaths*

Likelihood Category Examples

1. Remote - *1 in a million or less per year*
2. Extremely Unlikely - *between 1 in a million and 1 in 100,000 per year*
3. Very Unlikely - *between 1 in 100,000 and 1 in 10,000 per year*
4. Unlikely - *between 1 in 10,000 and 1 in 1,000 per year*
5. Likely - *between 1 in 1,000 and 1 in 100 per year*

The likelihood categories can be related to a ship life. For example, assuming a ship lifetime is 25 years, then for a scenario with an annual likelihood of 1 in a million (i.e. rating 1 Remote) the probability of occurrence in the ship's lifetime is 1 in 40,000 (i.e. $1/(10^{-6} \times 25)$).

Risk Rating and Risk Criteria Examples

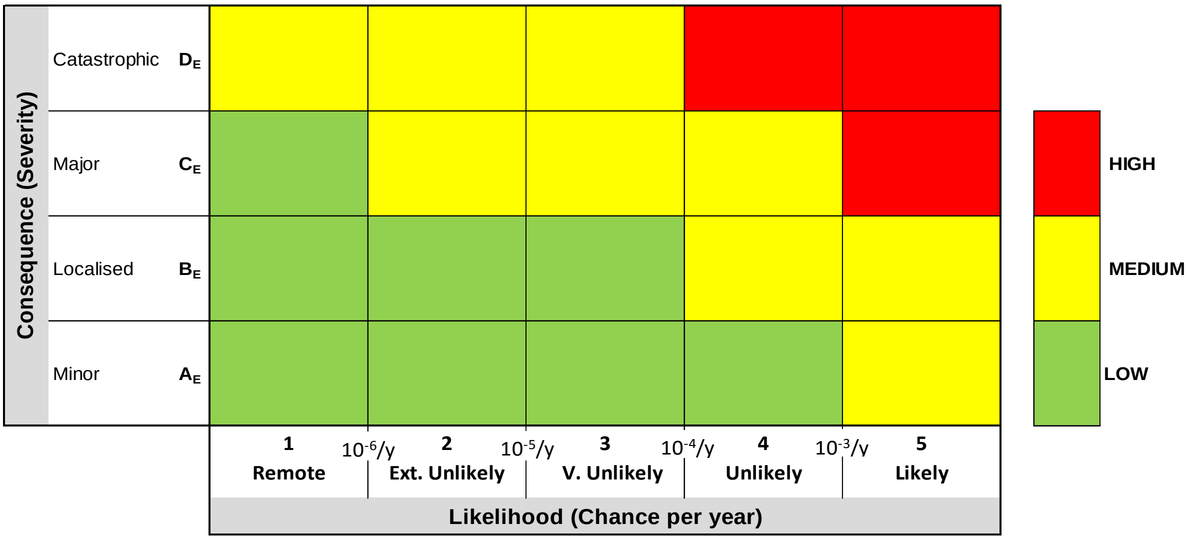
Low Risk – A_P1, A_P2, A_P3 & B_P1
The risk can be accepted as 'mitigated as necessary'. Where practical and cost-effective it is good practice to implement mitigation measures that would further reduce the risk.

Medium Risk – A_P4, A_P5, B_P2, B_P3, B_P4, C_P1, C_P2 & C_P3
The risk is tolerable and considered 'mitigated as necessary'. This assumes that all reasonably practicable mitigation measures have been implemented. That is, additional or alternative mitigation measures have been identified and implemented unless judged impractical or the cost of implementation would be disproportionate to the reduction in risk.

High Risk – B_P5, C_P4 & C_P5
The risk is unacceptable and is not 'mitigated as necessary'. Additional or alternative mitigation measures must be identified and implemented before operation, and these must reduce the risk to medium or low.

No. 146 (cont)

Risk Matrix Example – environment



Consequence Category Examples

A_E Minor - *limited and reversible damage to sensitive areas/species in the immediate vicinity*
B_E Localised - *significant but reversible damage to sensitive areas/species in the immediate vicinity*
C_E Major - *extensive or persistent damage to sensitive areas/species*
D_E Catastrophic - *irreversible or chronic damage to sensitive areas/species*

Likelihood Category Examples

1. Remote - *1 in a million or less per year*
2. Extremely Unlikely - *between 1 in a million and 1 in 100,000 per year*
3. Very Unlikely - *between 1 in 100,000 and 1 in 10,000 per year*
4. Unlikely - *between 1 in 10,000 and 1 in 1,000 per year*
5. Likely - *between 1 in 1,000 and 1 in 100 per year*

The likelihood categories can be related to a ship life. For example, assuming a ship lifetime is 25 years, then for a scenario with an annual likelihood of 1 in a million (i.e. rating 1 Remote) the probability of occurrence in the ship's lifetime is 1 in 40,000 (i.e. $1/(10^{-6} \times 25)$).

Risk Rating and Risk Criteria Examples

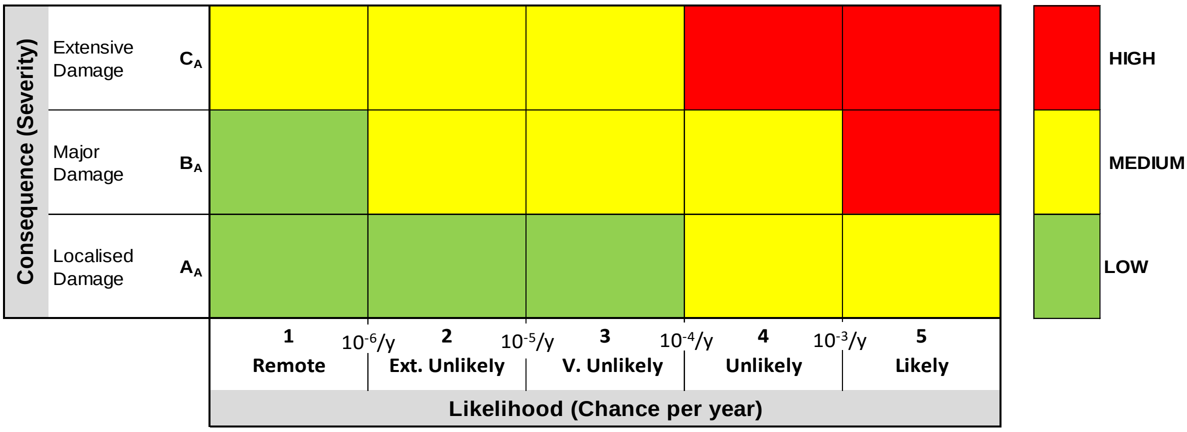
Low Risk – A_E1, A_E2, A_E3, A_E4, B_E1, B_E2, B_E3 & C_E1
The risk can be accepted as 'mitigated as necessary'. Where practical and cost-effective it is good practice to implement mitigation measures that would further reduce the risk.

Medium Risk – A_E5, B_E4, B_E5, C_E2, C_E3, C_E4, D_E1, D_E2 & D_E3
The risk is tolerable and considered 'mitigated as necessary'. This assumes that all reasonably practicable mitigation measures have been implemented. That is, additional or alternative mitigation measures have been identified and implemented unless judged impractical or the cost of implementation would be disproportionate to the reduction in risk.

High Risk – C_E5, D_E4 & D_E5
The risk is unacceptable and is not 'mitigated as necessary'. Additional or alternative mitigation measures must be identified and implemented before operation, and these must reduce the risk to medium or low.

No. 146 (cont)

Risk Matrix Example – ship assets (equipment, spaces and structure)



Consequence Category Examples

A_A Localised damage - *an event halting operations for more than x days*
B_A Major damage - *an event halting operations for more than y days*
C_A Extensive damage - *loss of ship, an event halting operations for more than z days*

Likelihood Category Examples

1. Remote - *1 in a million or less per year*
2. Extremely Unlikely - *between 1 in a million and 1 in 100,000 per year*
3. Very Unlikely - *between 1 in 100,000 and 1 in 10,000 per year*
4. Unlikely - *between 1 in 10,000 and 1 in 1,000 per year*
5. Likely - *between 1 in 1,000 and 1 in 100 per year*

The likelihood categories can be related to a ship life. For example, assuming a ship lifetime is 25 years, then for a scenario with an annual likelihood of 1 in a million (i.e. rating 1 Remote) the probability of occurrence in the ship's lifetime is 1 in 40,000 (i.e. $1/(10^{-6} \times 25)$).

Risk Rating and Risk Criteria Examples

Low Risk – A_A1, A_A2, A_A3 & B_A1
The risk can be accepted as 'mitigated as necessary'. Where practical and cost-effective it is good practice to implement mitigation measures that would further reduce the risk.

Medium Risk – A_A4, A_A5, B_A2, B_A3, B_A4, C_A1, C_A2 & C_A3
The risk is tolerable and considered 'mitigated as necessary'. This assumes that all reasonably practicable mitigation measures have been implemented. That is, additional or alternative mitigation measures have been identified and implemented unless judged impractical or the cost of implementation would be disproportionate to the reduction in risk.

High Risk – B_A5, C_A4 & C_A5
The risk is unacceptable and is not 'mitigated as necessary'. Additional or alternative mitigation measures must be identified and implemented before operation, and these must reduce the risk to medium or low.

No. 146 (cont)

Appendix 5
Likelihood of releases

Indicative likelihood categories

The following table provides indicative likelihood categories as follows: (a) named equipment item fails and releases fuel[20], and (b) collisions and groundings[21].

Likelihood values differ dependent upon source, assumptions made and the inclusion/ exclusion of causes, etc. Therefore, it is important to refer to the original data sources to ensure the indicative likelihood category remains valid for specific cases of interest.

Indicative Likelihood Values by Likelihood Category

1. Remote - 1 in a million or less per year (10^{-6}/y or less)			
Type C Fuel Tank	<1 x 10^{-6}		
2. Extremely Unlikely - *between 1 in a million and 1 in 100,000 per year* *(10^{-6}/y to 10^{-5}/y)*			
Leak ≥ 10 mm Ø	**50 mm or less Ø**	**51-150 mm Ø**	**151-300 mm Ø**
Pipework / per metre	7 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}
Flange	4 x 10^{-6}	5 x 10^{-6}	7 x 10^{-6}
Manual Valve	---	7 x 10^{-6}	9 x 10^{-6}
3. Very Unlikely - *between 1 in 100,000 and 1 in 10,000 per year* *(10^{-5}/y to 10^{-4}/y)*			
	50 mm or less Ø	**51-150 mm Ø**	**151-300 mm Ø**
Pipework / per metre	8 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}
Flange	4 x 10^{-5}	5 x 10^{-5}	8 x 10^{-5}
Manual Valve	3 x 10^{-5}	5 x 10^{-5}	7 x 10^{-5}
4. Unlikely - *between 1 in 10,000 and 1 in 1,000 per year* *(10^{-4}/y to 10^{-3}/y)*			
	50 mm or less Ø	**51-150 mm Ø**	**151-300 mm Ø**
Actuated Valve	3 x 10^{-4}	3 x 10^{-4}	3 x 10^{-4}
Instrument Connection	3 x 10^{-4} includes flange		
Process Vessel	7 x 10^{-4} pressurised vessel		
5. Likely - *between 1 in 1,000 and 1 in 100 per year* *(10^{-3}/y to 10^{-2}/y)*			
		50-150 mm Ø	**>151 mm Ø**
Heat Exchanger / Evaporator / Heater		2 x 10^{-3}	2 x 10^{-3}
Pumps (centrifugal or reciprocating)		5 x 10^{-3}	1 x 10^{-3}
Ro-Pax	1 x 10^{-2} collision / 1 x 10^{-2} grounding		
Cruise Ship	5 x 10^{-3} collision / 1 x 10^{-2} grounding		
Container Ship	2 x 10^{-2} collision / 7 x 10^{-3} grounding (data refers to wrecked/stranded)		
The likelihood values include all collisions and groundings. For collisions this means all collisions where the ship is 'struck' and where the ship is the 'striking ship'. The likelihood of interest might be less than the values above when consideration is given to ship, route and incident specifics. For example, assuming a release requires a Ro-Pax ship to be 'struck' and the collision to be 'serious' then the likelihood value approximates 5 x 10^{-4} (i.e. category 4 'Unlikely' where 'struck/striking' is assumed 50/50 and about 10% of collisions are 'serious'[21]).			

20. Indicative values are based on (a) and (b) and summarised in (c): (a) International Association of Oil & Gas Producers. (1 March 2010). Risk Assessment Data Directory – Process Release Frequencies, Report No. 434 – 1; (b) Health and Safety Executive. (1992-2006). Hydrocarbon Releases (HCR) System. https://www.hse.gov.uk/hcr3/; (c) LNG as a Marine Fuel - Likelihood of LNG Releases. Journal of Marine Engineering & Technology (JMET), Vol. 12, Issue 3, September 2013.
21. Formal Safety Assessment (FSA): FSA Container Vessels, MSC 83/21/2 (Table 3), 3 July 2007; FSA Cruise Ships, MSC 85/17/1 (Table 1), 21 July 2008; and FSA RoPax Ships, MSC 85/17/2 (Table 1), 21 July 2008.

No. 146 (cont)

Appendix 6
Mitigation measures

Example mitigation measures

Engineering Mitigation Measures
Protection from mechanical impact damage
Protection from vibration / vibration monitoring
Protection from wind, waves and weather
Pressure relief, venting
Increased separation or increased physical protection from collision / grounding
Secondary containment (e.g. double-walled pipework)
Welded connections in preference to flanged connections
Alarmed and self-closing doors
Bulkhead separation / cofferdam
Drip tray capacity, liquid detection
Spray shield coverage
Protection of structure from cryogenic temperatures and pressure from evolved vapour / gas
Independent bilge
Fire and gas detection, monitoring, audible / visual alarm and shutdown
Pressure and temperature detection, audible / visual monitoring, alarm and shutdown
Level detection
Forced / natural ventilation - airlock
Minimisation of ignition sources - Ex proof electrical equipment
Fire-fighting fire and cooling appliances - foam, water spray
Fire dampers
Separation of spaces
Access arrangements
Physical shielding
Mooring tension monitoring / alarm
Strain monitoring of supports
Buffer / overflow tank - Fuel recycling
Independent safety critical controls to IEC 61508
Radar monitoring
Service fluid - level / gas detection, alarm and shutdown
Flame arrestor
Procedural Mitigation Measures
Increased frequency of inspection (and maintenance)
Reduced parts replacement frequency
Specific training for low-flashpoint fuels
Restricted access
Monitoring

Note:

1. The mitigation measures above are largely generic and in no particular order. They are listed as a simple *aide memoir* when considering mitigation.
2. Within the IGF Code, measures to reduce likelihood and measures to reduce consequences are both understood to be mitigation measures (i.e. they mitigate the risk). To align with the IGF Code this understanding is maintained within this document. It is recognised that in many other industries it is common to use the terms ‘prevention measures’ and ‘mitigation measures’, where the former reduces likelihood and the latter reduces consequences. Prevention and mitigation measures are often referred to as ‘safeguards’ or ‘barriers’.

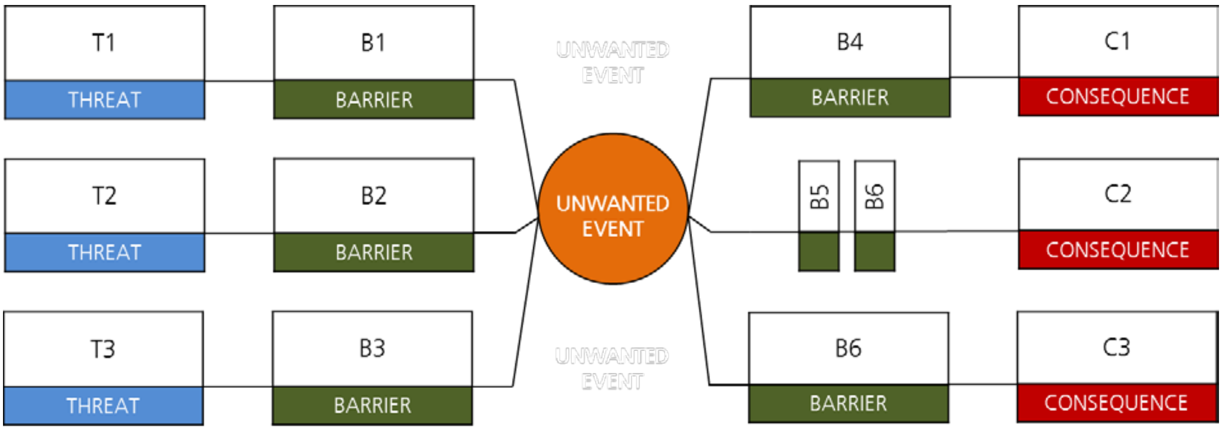
No. 146 (cont)

Appendix 7
Cause to Consequence Mapping

An established means to illustrate or map the pathway from ‘cause’ to ‘consequence’ is known as Bowtie. There are a number of variations on this theme and differing terminologies but essentially the Bowtie helps to visualise: threats or causes of an unwanted event; the barriers or mitigation measures to prevent the unwanted event; and the barriers to mitigate the consequences.

Bowtie examples

Threat – *A cause that can potentially lead to the unwanted event.*
Barrier – *A mitigation measure that can potentially prevent the unwanted event or its consequences.*
Unwanted Event – *A situation to be avoided e.g. a release of fuel or a loss of ship propulsion.*
Consequence – *An outcome of a threat and an unwanted event not being mitigated by the barriers.*



In respect of ‘mitigation measures’ (i.e. barriers) those prior to the unwanted event are often referred to as preventative barriers or prevention measures.

No. 146 (cont)

Appendix 8
Report Contents

Example report contents

Executive summary	
An overview of the assessment and main results and conclusions.	
1. Introduction	
A brief statement on the purpose of the assessment and the parties involved.	
2. Objective and Scope	
The principal objective is, for example, to demonstrate that the safety-risk is, or can be made acceptable/tolerable for Class approval. The scope is, for example, limited to the design/arrangement, the specific environment/location and the intended modes of operation.	
3. Description	
A simple explanation of the design and arrangement with respects to its intended operation and process conditions.	
4. Approach	
Overview of the risk assessment technique/method. This includes how the design was divided into sections for assessment, how hazard identification was undertaken, the selection of risk criteria, and the mechanism of risk rating and recording. In addition, a note on the actual workshop schedule illustrating the time expended on each section.	
5. Team	
The names, job titles, relevant qualifications, expertise and experience of the facilitator and SMEs. This can be recorded in a table, together with a record of workshop attendance. If this information is particularly large and would detract from the approach and results, the information can be included as an appendix.	
6. Results	
Discussion of the main findings and issues.	
7. Conclusions	
A summary judgement on whether the risks are 'mitigated as necessary'.	
8. Actions	
A listing of additional/alternative safeguards, including who is responsible and expected completion date.	
Appendices	
A.	Worksheets (as recorded in the workshop, including guidewords and phrases i.e. prompts).
B.	Drawings, Process Information and Reference Documents (including the Terms of Reference).

End of Document

No. 146
(2016年8月)

《IGF 规则》要求的风险评估

1.1 通则

为消除或降低使用低闪点燃料时的风险，船舶应按 IGF 规则[1]要求进行风险评估。风险评估应使用“可接受的”和“公认的”技术，并形成主管机关满意的文件。

目前，有多种“可接受的”和“公认的”风险评估技术和记录风险评估文档的方法。正因如此，本建议案并不旨在限定风险评估的具体技术或文档记录方法，而是描述满足 IGF 规则的推荐做法和实例。

1.2 风险评估 – 目的

如 IGF 规则中所述，风险评估的目标或目的是 *“消除或减轻对船上人员、环境或船舶的任何不利影响”*[2]，即消除或减少因使用低闪点燃料而可能导致的人员伤亡、环境污染和船舶损害的意外事故。

1.3 风险评估 – 范围

IGF 规则要求风险评估范围应能覆盖低闪点燃料的使用[3]。这意味着此类燃料供给的风险评估工作涵盖：

- 船上安装的燃料接收、储存、整备（视需要）设备和与一台或多台发动机、锅炉或其他用气设备配套的燃料传输设备；
  这些设备包括总管、阀件、管路、货舱、泵/压缩机、热交换器和燃料供给系统检测仪表。

- 操作控制设备
  例如：压力、温度调节器和监视器，流量控制器，信号处理器和控制面板。

- 探测、报警和安全启动设备
  例如：探测器检测到燃料释放，随后着火，安全启动设备切断燃料供给。

- 除预定设备外（即《IGF 规则》未规定）的通风、围护和处理设备
  例如：通风管路、桅杆、阀件、溢流舱、次屏壁和通风设备。

- 消防设备，用以保护船体表面免受火灾，防止燃料接触和火势蔓延。
  例如：水雾喷淋系统，水幕系统和挡火闸。

- 燃料管路驱气和惰化装置
  例如：存储和供给氮气的设备，用以安全传输/处理燃料的设备。

- 处所的结构和构造
  例如：燃料存储处所，燃料舱接头处所和燃料准备间。

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1. 使用气体或其他低闪点燃料船舶国际安全规则 (IGF 规则) - MSC 95 决议采用 (2015 年 6 月).
2. 参见 IGF 规则, 部分 A, 第 4 章, 4.1
3. 参见 IGF 规则, 部分 A, 第 4 章, 4.2.1.

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当与利益相关方（如主管机关）达成一致时，之前已进行过风险评估的项目可从该范围中去除，但须表明其“应用场景”未发生改变，并提供基于之前风险评估结果所采取的相应的风险应对措施。这有助于减少评估的时间和工作量。.

术语“应用场景”（上段所述）涉及应用场景的差异，比如设计或布置差异、安装位置差异、运行模式差异、周围空间使用的差异和暴露人员的数量与类型的差异。例如，对于某一物品放置在货船的甲板上的情形，当同样的物品放置在客船的甲板下时，其“应用场景”即发生了改变。在分析“应用场景”时，重点在于识别这些“差异”是否会显著地减少或增加风险，从而导致需要减少、增加或改变风险消除或降低的方法。

关于液化天然气（LNG），IGF 规则规定风险评估“仅需在 5.10.5、 5.12.3、 6.4.1.1、6.4.15.4.7.2、8.3.1.1、 13.4.1、 13.7 和 15.8.1.10 以及附录 4.4 和 6.8 有明确要求的情况下进行”[4]。所以，IGF 规则允许风险评估的范围仅限于上述条款。值得注意的是，按照上述条款的要求，对于风险评估的范围可能会产生分歧。因此， 当确定风险评估的范围时，应征询利益相关方的意见并获得主管机关的批准。

风险评估需考虑船上燃料加注设备的影响，但不考虑加注操作的影响，加注操作包括：到船、靠泊、系泊、准备、测试、连接、燃料输送、加注完成和断开连接。船舶燃料加注应按照 ISO/TC18683 单独进行评估，并制定合适具体的指导性文件以供参考。

IGF 规则要求风险评估应考虑设备的实际布置、操作和维护。通常，与维护有关的风险会在实际操作前经由具体的风险评估工作得以控制。因此，所考虑的设备维护是指在较高层面上考虑设备的设计和布置，使其在安全合适的环境下工作。需要考虑的方面，例如：设备绝缘、处所通风、紧急疏散、加热、照明和通向设备的通道。这样做的目的是最大限度地减少维护期间因意外事故造成损害的可能性。另外，其目的同样在于减小因工作环境恶劣致使维护工作不足从而导致维护工作后发生意外事故的可能性。

评估还应重视潜在的系统集成问题，例如设备控制和连接兼容性。当复数利益相关方参与独立设备的设计、供应、建造和安装时，这一点尤为重要。

职业风险可从风险评估中移除。职业风险是一个重要的安全考虑因素，将被包含在船舶安全管理体系之中。

评估范围应涵盖船上装置的设计和布置。因此，当最终确定设计方案之前，需要进行并修正风险评估，使得风险能够“视需要减轻”。

IGF 规则没有提及风险评估的定期更新。更新应在设备设计/布置和/或其操作发生变化时进行，以响应设备和控制的性能变化。这有助于确保燃料系统的整个生命周期中，风险能够“视需要减轻”。

风险评估的最终范围应与适当的利益相关方（如主管机关）达成一致并遵循适用的船级社规则和 IGF 规则。

1.4 风险评估 – 方法

IMO 已经发布了关于综合安全评估（FSA）的指南，并提供了有关风险评估方法和标准的

4. 参见 IGF 规则，部分 A-1，第 4 章，4.2.2.

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有用信息 [5]。 指南的目的是帮助评估海上安全和环境保护方面的新法规。评估侧重于风险量化分析和成本效益分析，以便为决策提供依据。因此，它对于 IMO 风险评估标准是十分有价值的参考。然而，IGF 规则不要求对因使用燃料而给人员、环境和财产带来的风险进行定量评估。风险评估只需要提供信息，以助于确定是否需要采取进一步措施来“消除”风险或确保风险能够“视需要减轻”。因此，采用定性或半定量评估方法是适当的（即定性风险评估，QualRA[6]）。 这并不是指完全量化的方法是不适当的，或者说情况不适合使用完全量化法（即定量风险评估, QRA）。重要的是，风险评估应具有足够的深度，以便证明风险已被“消除”或“视需要减轻”。

风险评估至少应详细说明：

A. 低闪点燃料如何潜在地造成危害 – 危险识别；
即是说，系统地识别可能导致例如重大伤亡、环境污染和/或船舶结构强度或完整性破坏的意外事件。

B. 危害的潜在严重程度 – 后果分析；
即是说，危害的潜在严重性（即后果）表现在，例如重大伤害、单人或多人死亡、不良环境影响和足以损害安全操作的结构/船舶损伤。

C. 危害的可能性 – 可能性分析；
即是说，危害可能发生的概率或频率。

D. 风险的度量 – 风险分析；
即是说，结果(B)和可能性(C)的组合。

E. 风险接受的判断 – 风险评估；
风险度量（D）应与标准进行比较，以便判断风险是否已“视需要减轻”

ISO 31010[7], ISO 17776[8], ISO 16901[9], NORSOK Z-013[10], CPR 12E[11] 和 CCPS[12] 与 HSE[13] 出版物等描述了满足上述要求（即 A-D）的可接受和公认的技术。

下文 A1.4.1 概述了满足上述要求的方法。

1.4.1 满足 IGF 规则要求的方法 – 定性风险评估（QualRA）

A. 危险识别

1. 根据设备的功能和位置将燃料系统分为的不同的部分
这有助于系统地考虑系统的每个部分，并有助于识别与特定项目、活动或部分有关的意外事故的具体原因。系统的典型划分可以是，例如：(a)加注站和到燃料舱的燃料管路；(b)燃料储藏处所；(c)燃料舱接头处所；(d) 燃料准备间；(e) 发动机燃料输送管路和阀

5. 用于 IMO 规则制定过程中的正式安全评估修订指南。MSC-MEPC.2/Circ.12, 2013 年 7 月 8 日
6. 在发生某种形式的量化时，该方法是半定量的。 然而，这样的方法通常被称为定性的，且该术语在本文中使用。
7. 风险管理：风险评估技术。IEC/ISO 31010:2009.
8. 石油和天然气工业 – 海上生产设施 – 关于危险识别和风险评估的工具和技术指南。EN ISO 17776:2002.
9. 陆上 LNG 设施（包括船岸界面）设计风险评估指南。 ISO/TS 16901:2015.
10. 风险与应急预案评估，NORSOK 标准 Z-013, 第 3 版, 2010 年 10 月
11. 概率的确定与处理方法，CPR 12E, 1997/2005.
12. 例如：化学工艺定量风险分析指南。化学工艺安全中心，美国化学工程师协会，第二版，2000.
13. 例如：海上风险评估。健康与安全局，2001.

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件。

2. 展开一组可能导致意外事件的引导词/词组和示例原因（如燃料释放或燃料系统故障导致动力损失）。
引导词/词组和示例原因被用来当作提示。附录1 中给出了一个典型但不详实的提示列表。

3. 通过参考设计和布置信息、位置图、工艺流程图、减轻措施和应急计划，运用提示识别意外事件的潜在原因（如燃料释放和动力损失）。
在协调人领导和学科领域专家参与下，这些提示将被用于在研讨会上激发思想和讨论。

4. 记录意外事件的潜在原因和减轻措施
记录表或工作表的示例在附录2 中给出。此工作表还用于记录以下步骤B 至E，并构成风险评估的整体文档的一部分。

B. 后果分析

5. 对于每个被识别的原因，估计潜在后果，例如，重大伤害、单人或多人死亡、不良环境影响和足以损害安全操作的结构/船舶损伤。
潜在后果可由学科领域专家（SMEs）判断，并参考：(a) 燃料特性/危险性; (b) 释放位置; (c)扩散/泄漏路径; (d) 点火源位置和“强度”; (e) 与易损接收装置的距离; (f) 通用或（如受委托）特定的火灾和爆炸模型; 和 (g) 现有/计划的减轻措施的预期效果。附录3 总结了(a)中所述的液化天然气(LNG)的特性和危险性。

6. 对预计后果进行分类。.
后果可由学科领域专家(SMEs) 依据严重程度的指示进行分类。例如，对人员伤害的类别可以分为重大伤害、单人死亡和多人死亡。后果分类示例在附录4 中给出。

C. 可能性分析

7. 估计“原因和后果”每年发生的可能性。
可能性可由学科领域专家（或具备适当资质的个人）为每一组“原因–后果”或具有相同后果的一组原因进行评估。通过参考事故和未遂事故报告、事故和设备发布数据、类似或其他行业中的同类事故，以及考虑风险减轻措施的可靠性和有效性，为评估工作提供资料。“原因-后果”组合并不一直是明显可信的（即可合理预见的）。作为指南，如果出现下列情形，则该意外事件可被视为可信的：(a) 事件曾经发生过，也可能再次发生；(b) 事件并没有发生，但其每年发生的概率被认定为大于等于百万分之一；(c) 事件是计划内的，即是说，应急响应计划包括了该意外事件，或进行了维护保养工作以防止该事件发生。有关LNG 设备和操作泄漏可能性的指南见附录5.

8. 预计的可能性分类。
可能性可由学科领域专家（或具备适当资质的个人）加以分类，以指示事故或意外事件发生的概率。可能性分类的示例在附录4 中给出。

D. 风险分析

9. 估计风险。
学科领域专家（或具备适当资质的个人）可以通过结合后果和可能性分类来估计风险，以提供风险评级。例如，如果一对“因果后果”对被分类为“A”，并且相关联的“可能性”被分类为“1”，则风险评级为“A1”。风险评级方案的一个示例在附录4 中给出。

E. **风险评估**

10. 判断风险是否已“视需要减轻”
可以将预计的风险与嵌入在风险矩阵内的风险标准进行比较。风险矩阵显示了风险评级（关于结果和可能性）且风险标准阐明了风险是否已“视需要减轻”。风险评级机制及相关风险标准的示例在附录 4 中给出。

关于上述的 D 和 E，目前没有普遍认可的风险评级方案或风险标准：政府、监管机构和不同组织机构之间存在差异。因此，在开展风险评估之前，风险评级/标准应征得适当的利益相关方的同意（如主管机关）。

并且，单个或一组“原因-后果”的风险评级无法为来自于所有潜在“原因-后果”的集体（总体）风险提供指示。 如果需要总体风险水平，可以使用 QRA 确定。

实际上，风险评级表明了附加或替代的减轻措施：

- 必须提供；或
- 如切实可行且具有成本效益，则必须考虑并实施；或
- 不需要进一步考虑，除非有切实可行的可接受的良好措施用以降低风险。

在上述每个步骤中，都进行了许多假设，并且存在不确定性。因此，学科领域专家的良好做法是列出假设并“测试”结果对任何这些步骤变化的敏感性。例如，对已指定的后果或可能性分类进行改变，则可能改变风险评级和关于风险是否已“视需要减轻”的判断。

1.4.1.1 视需要减轻

“视需要减轻”一词在 IGF 规则中的使用类似于短语“合理可行地减轻”，通常被简称为 ALARP。实际上，如果所有合理可行的减轻措施均被实施，则该风险可被视为 ALARP。这意味着，已经识别且实施了附加或替代措施用以降低风险，除非这些措施被证明是不切实际的或其执行成本与可减少的风险不成比例。ALARP 这一概念是许多行业的惯例，并被 IMO[14] 认可为最佳做法。

如果“视需要减轻”无法被证明，那么学科领域专家应考虑附加的和/或替代减轻措施 [15]，并重新评估风险。**在实现风险的“视需要减轻”之前，该风险不可被视为 “可接受的”。** 就这一点而言，可以通过进一步研究来帮助学科领域专家确定现有的附加或替代措施是否可提供风险的“视需要减轻”。

在考虑减轻措施时，以下的**减轻层级**被认为是最佳做法：:

- 首先，采取措施防止意外事件的发生；
即确保意外事件不会发生或使其发生的可能性大大降低；

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14. 经修正的用于 IMO 规则制定过程的正式安全评估指南. MSC-MEPC.2/Circ.12, 2013 年 7 月 8 日

15. 在 IGF 规则中, 降低可能性的措施和减轻后果的措施均可被理解为减轻措施 (即他们均能减轻风险). 为了与 IGF 规则中保持一致, 本文中保留了这一理解. 可以认识到在许多其他行业中, 通常使用术语“预防措施”和“缓解措施”, 前者降低风险的可能性而后者减轻风险的后果. 预防和减轻措施通常被称为“保障措施”或“屏障”.

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- 其次，采取保护措施，免受意外事件的伤害；
  即减少意外事件后果的不利影响。

另外，在考虑减轻措施时，好的做法是**优先考虑工程解决方案而不是控制程序**。这有助于促进本质上更安全的设计。除此之外， 好的做法是**优先考虑被动措施而不是主动措施**。例如，被动措施是指不需要手动或自动动作就能使其按需工作的措施。相反的，主动措施需要激活一些装置来操作。可能需要证明所采取的被动措施和主动措施能够使风险“视需要减轻”。减轻措施的示例在附录 6 中给出。

说明或映射从“原因”到“后果”的路径，并审查减轻措施的有效性将有助于判断减轻措施是否有效。 映射和审查的一个示例在附录 7 中给出。

一个单一的减轻措施或一系列减轻措施是否切实可行并具有成本效益，在某些方面与可利用的资源和技术有关。如果学科领域专家无法做出决定，则可以进行成本效益分析，这将有助于学科领域专家做出决定。无论如何，如果学科领域专家判断该措施不是切实可行的并具有成本效益时，那么应当制定一个没有实施减轻措施的合理性说明文件。

1.5 风险评估 – 团队

进行风险评估的小组应由学科领域专家（SMEs）组成，学科领域专家须具有合适的资质并富有经验。对于上述定性风险评估（QualRA），这意味着研讨会团队应包括：拥有相关专业学位的个人和/或特许/专业工程师、具有船舶操作经验的个人和具有风险评估经验的个人。这些资质和经验应在相关专业中涵盖工程设计和燃料的安全使用。

一个学科领域专家（SME）不太可能满足上述团队的要求。无论如何，为确保研究讨论、想法产生、质疑挑战的顺利进行并且覆盖较大范围，例如机械、工艺、电气和操作方面，一般来说需要 4 到 8 名学科领域专家。

除了学科领域专家，团队应由一个协调人（也称为主席）领导。协调人应该公正，没有与燃料系统有关的既得利益，并且在领导这种风险评估方面富有经验。协调人可以由抄写员（也称为秘书）辅助以完成报告。

团队花费的时间取决于约定的风险评估范围和设计的“复杂性”。 例如，针对新设计的定性风险评估（QualRA）研讨会可能需要两到三个工作日，而对以前评估和批准过的设计进行微小改动可能只需要半天。

1.6 风险评估 – 报告

1.6.1 主要报告

应编制一份书面报告以记录风险评估。报告需要足够详细，以支持结果、结论、建议和采取的任何行动。这是因为评估报告将为重大的设计和运营决策提供信息。此外，该报告是帮助证明风险“视需要减轻”的记录。一份仅由完整工作表组成的报告是不足的。

报告的具体内容及其结构取决于设计和评估的细节以及报告的倾向性。然而，对于一份定性风险评估（QualRA），报告中应提供：

- 设计和布置的概述；

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概述简单解释了与设计和布置相关的预期操作和工艺条件。技术附录应包括工艺流程图、总布置图和评估过程中使用的所有信息。如果在报告中完全包含这些内容太繁杂，则可以仅需提供这些材料的参考资料，只要这些参考资料是可用的。

- 风险评估过程的解释；
  这是对风险评估方法的描述，包括如何将设计分为几部分进行评估，如何进行危险源辨识，和如何选择后果和可能性分类，以及风险标准。

- 团队相关资格和专业知识的信息；
  可以用表格列出所有团队成员（包括协调人和抄写员）的姓名、职称、相关资格、专长和经验。仅仅列出姓名和工作职位的表格是不够的。

- 完成评估所需的时间以及学科领域专家的出席并提供专家意见的情况；
  对于研讨会，可以用表格列出每个学科领域专家的出席日程/时间和出勤率（即全勤或部分出席，如果是部分出席则列出该专家缺席的“部分”）。这样做的目的是表面评估设计/布置的时间是否足够，并突出任何学科领域专家的缺席所可能带来的对评估结果、结论和行动的不利影响。对于任何学科领域专家的缺席，协调人应提供一份说明，说明这是否对所作的假设和判断产生不利影响。

- 风险结果和结论；
  这是对结果的列举或讨论，以及判断风险是否已“视需要减轻”。

- 建议和行动。
  建议和行动可包括对建模和分析的要求（例如气体扩散或热辐射范围等），并且将很可能包括要研究和/或实施的附加及替代的减轻措施，负责人，以及预期的完成时间（如果已知的话）。重要的是，这些建议和行动应有适当的文件记录，因为它们可能用于计划响应和监测进展，直到建议/行动得到解决。

一个报告目录的示例在附录 8 中给出。

1.6.2 报告范围 (ToR)

在开展研讨会之前，好的做法是由协调人向团队发布相关信息。这有时系指报告范围（ToR）。这有助于团队在研讨会之前熟悉设计和预期的方法。它还为被提议的后果和可能性分类及风险标准的澄清和达成共识提供了时间。 更重要的是，它为确认拟议的日程表和团队是否合适提供了时间。报告范围（ToR）可以形成主报告的附录。

通常，报告范围（ToR）包括：

- 评估的目标和范围；
  这是为了确保所有团队成员都了解评估目标，以及评估涵盖了哪些设备和操作。

- 拟议的设计和布置的技术说明；
  可以包括以下图纸的复印件：工艺流程图（PFDs）或详细说明设备和管道工艺条件的原理图，以及说明设备和管道布置、尺寸和位置的比例布置图。

- 燃料泄漏的潜在后果概述；
  对于 LNG，可参考本文的附录 3。

- 运用的技术；

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包括拟议的后果和可能性分类与风险标准。

- 预期的研讨会日程表；
  强调了研讨会所需的时间和学科领域专家需要投入的时间。

- 团队详细信息。
  包括了每个团队成员/研讨会参与者和学科领域专家的姓名、职称、相关资格、专业知识和经验。

No. 146 (cont)

附录 1
提示 – 引导词和词组

用于定性风险评估的提示 – 示例

包含燃料设备的失效 – 孔/裂纹导致的燃料泄漏	
磨损	*振动，载荷，循环运动，长期使用*
侵蚀	*燃料污染物，高速流，长期使用*
应力和应变	*振动，载荷，循环运动，船舶运动，长期使用*
疲劳	*振动，载荷，循环运动，船舶运动，长期使用*
腐蚀	*暴露于风雨，暴露于海水，湿气，干燥空气供给损失，接触腐蚀性物质*
碰撞	*与其他船舶碰撞，触礁，船舶撞击港口围墙或码头*
搁浅	*船舶搁浅*
撞击	*物体掉落（例如维护或货物装卸期间），支撑构件倒塌，装卸货物/维护期间的误操作*
火灾	*易燃材料着火，邻近处所/区域发生火灾*
**加上含有气体或其他可能释放到空气中造成危害的物质（例如窒息，烧伤）的设备*	
控制程序失效 – 设计条件之外的操作，随后导致燃料泄漏	
高温	*绝热失效，仪器故障，软件故障，执行机构故障，操作员操作不当，外部火灾，遭受极端天气，变质*
低温	*热循环介质损失，热介质污染，仪表故障，软件故障，执行机构故障，操作员操作不当，遭受极端天气*
高压	*操作员操作不当（例如错误关闭阀），公用设备损失（例如仪表气源），外部火灾，动力损失，翻滚，蒸发气体的过量产生，执行机构故障*
低压（真空）	*操作员操作不当，公用设备损失（例如仪表气源），电源供应损失（电力），执行机构故障*
流量过高	*仪器故障，软件故障，操作员操作不当，执行机构故障，遭受极端海况*
流量过低	*仪器故障，软件故障，操作员操作不当，执行机构故障，遭受极端海况*
流向反向	*仪器故障，软件故障，操作员操作不当（例如错误关闭阀），执行机构故障，遭受极端海况*
无流量	*仪器故障，软件故障，操作员操作不当（例如错误关闭阀），执行机构故障*
高液位	*仪器故障，软件故障，操作员操作不当，执行机构故障，遭受极端海况*
低液位	*仪器故障，软件故障，操作员操作不当，执行机构故障，遭受极端海况*
管路内燃料残留	*操作员操作不当，阀门关闭，无惰性/吹扫气源，有限的惰性/吹扫气源*
管路内无燃料	*仪器故障，软件故障，操作员操作不当，阀门关闭*
动力损失	*电信号丢失，断电，设备气源损失，液压油损失*

注意：设备的制造、安装和调试质量差将会增加燃料泄漏的可能性和/或后果。如果这些方面没有被，例如船级社规范，涵盖和控制，那么他们应当被纳入风险评估之中。评估应涵盖预期的操作、关机和启动。

No. 146 (cont)

附录 2
记录表/工作表

工作表 – 示例

工作表 [项目名称]												
篇或章 [名称]												
						分类 & 评分						
项目 / 活动	引导词 / 词组	原因 (事故 / 事件)	后果	减轻措施 (现有防护措施)	附加/替代减轻措施 (防护措施)	后果	可能性	风险	视需要减轻	建议 意见 / 措施	采取措施 / 日期

注意：在考虑附加/替代防护措施之前和之后，该工作表可通过“现有防护措施”和“附加/替代防护措施”记录风险等级。如果愿意，可将“附加/替代减轻措施(防护措施)”移动至“分类&评分”列之后，并在其后添加额外的“分类&评分”列。

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(cont)

附录 3
液化天然气的特性和危险性

3.1 LNG 特性

液化天然气 (LNG) 是低温液体。它由甲烷和少量的乙烷、丙烷和惰性氮气组成。当它用作燃料时，通常甲烷含量为 94%或更高。当储存在环境压力或近似环境压力下，其温度接近零下 162 ℃，其比重约为 0.42。因此，如果释放到海上 LNG 将漂浮（并可以迅速“沸腾” – 参见 3.2.7）。当在高达 10 bar 的压力下储存时，温度通常保持低于零下 130℃，比重约为 0.4。

当释放到大气中时，LNG 迅速沸腾形成无色、无味和无毒的气体。虽然无色，但由于其温度非常低，会与空气中的水蒸气冷凝形成可见的雾或云。低温气体最初比空气重，并且保持负浮力，直到其温度上升到约零下 100℃ 。在这个阶段，气体变得比空气轻，并且在开放环境中，认为这与气体浓度小于 5%一致。在该温度和浓度下，气体仍形成可见云。当气体继续升温至环境温度时，其体积为液体体积的近 600 倍，其相对蒸气密度约为 0.55，因此比空气轻得多（空气相对蒸气密度 = 1）。

随着 LNG 气体的扩散，其浓度降低。当其在空气中的浓度达到 5%至 15%之间时， 混合气体是可燃的，并且可以在点火源存在下点燃，或者与大约 595℃的热源接触时点燃。一旦浓度低于 5%，混合气体不再是可燃的，并且不能被点燃（如果浓度保持在 15%以上，也是这种情况）。空气中 LNG 浓度达到 15%和 5%通常分别被称为可燃性上限和可燃性下限。最近，该极限也被称为爆炸上限和爆炸下限，虽然点燃可能不一定导致爆炸。

3.2 LNG 的危险性

3.2.1 低温冻伤

由于其非常低的液体温度，与 LNG 接触将导致皮肤低温冻伤。此外呼吸冷气体，由于气体“沸腾”将导致肺损伤。冻伤与肺损伤的严重程度与液体/气体接触的表面积和暴露持续时间直接相关。

3.2.2 低温脆化

在接触低温 LNG 时，许多材料将失去延展性并变脆。 包括通常用于船舶结构和甲板的碳钢和低合金钢。这种低温催化可导致材料断裂，使得接触的材料中的现有应力甚至在没有另外的冲击、压力或使用的情况下导致开裂和失效。在 LNG 环境下工作时，应使用耐低温脆化的材料。这些材料包括：不锈钢、铝和高镍合金钢。

3.2.3 窒息

LNG 是无毒的，且不是已知的致癌物。然而当它沸腾形成气体时，它将置换并与周围空气混合，导致窒息。窒息的可能性与空气中的气体浓度和暴露的持续时间有关。

3.2.4 膨胀和压力

释放到空气中的 LNG 将迅速沸腾，产生的气体体积是液体体积的数百倍（在环境条件下大约 600 倍）。因此，如果气体持续膨胀并受限，压力将增加并可能导致周围的结构和设备损坏。

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3.2.5 火灾

3.2.5.1 池火

LNG“小量”释放将迅速沸腾并“闪蒸”成气体（即蒸发）。然而，当 LNG“大量”突然释放时，将形成 LNG 冷池，气体从池中沸腾并与周围空气混合扩散。如果该混合气体在可燃范围内（即空气中的 LNG 气体浓度为 5%至 15%）并且与点火源或高于自然温度（595 ℃）的加热表面接触，那么混合气体将被点燃并且所产生的火焰将“后退”到冷池，导致池火。

3.2.5.2 喷射火

如果 LNG 在压力下储存，则其释放可能以液体射流排放，夹带、蒸发并与空气混合。如果混合气体扩散并与点火源或加热表面（高于自燃温度）接触，同时其处于可燃范围内，则会点燃。所产生的火焰将“后退”并且可能导致释放源产生压力喷射火焰。 类似地，如果包含的 LNG 被加热并形成气体，则该气体的加压释放可以被点燃并导致喷射火产生。

3.2.5.3 闪火

LNG 释放到大气中并在几十秒内点燃将很可能导致池火或喷射火（如上所述）而不会产生超压损伤。这是因为可燃气体云可能相对较小并且在点燃时接近释放源。然而，如果点火延时，气体云将扩大并且可能从释放源进一步扩散。此时点燃将产生闪火，这是因为气体云中的可燃部分将在几秒内迅速消耗。此类点火很可能十分剧烈且可以听见，并且经常被误认为是爆炸，虽然没有明显的超压。

3.2.5.4 池火、喷射火和闪火的热辐射

人身伤害和火灾对建筑物和设备的损坏取决于火灾的大小、距离火灾的距离和暴露持续时间。距火灾 1 米内，其热辐射可高达 170 kW/m^2，但随着距离火灾的距离增加而迅速下降。

简易指南如下：

- 热辐射达到 6 kW/m^2 或以上时，逃生路线将受损，人员只有几分钟或更短的时间逃生以避免伤亡 [16]；
- 热辐射达到 35 kW/m^2 将导致人员立即死亡 [16]；
- 热辐射达到 37.5 kW/m^2 长期以来被视为暴露于稳态火灾下的工业设备和建筑结构的损害界限 [17]；
- 工业设备和建筑结构在闪火中不太可能受到明显损坏；和
- 在池火、喷射火或闪火中的人员很可能会受到致命伤害。

船舶上的 LNG 火灾可能导致人员死亡以及设备和船舶结构（包括船体）的损坏。

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16. 由于有许多不同来源的引用值不一致, 也可使用热剂量值作为代替. 此处使用的引用值来自于: 卫生安全局 – 适用于重大事故风险评估的海上人员风险指示, SPC/Tech/OSD/30, 2011; 和支持文件: 海上重大事故危险评估中关于人员风险的近似确定和评估方法. http://www.hse.gov.uk/foi/internalops/hid_circs/technical_osd/spc_tech_osd_30/spctecosd30.pdf
17. Rijnmond 地区六个潜在危险工业对象的风险分析, 试点研究, (1982). D. Reidel Publishing Company, 荷兰.

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3.2.6 爆炸

将 LNG 释放到空气中并将产生的可燃气体云延时数十秒点燃会导致爆炸。这是因为气体云可能已经扩散进入设备和结构及其周围空间，导致气体云被一定程度地限制并增加了其表面积，从而增加了火焰通过（即燃烧）可燃混合物的速度。爆炸所产生的超压可能足以对人员、建筑结构和设备造成危害。这类爆炸更像是爆燃（而不是爆轰），被归类为高速亚音速爆炸（即火焰通过可燃混合物的速率）。

3.2.6.1 爆炸超压

爆炸对人员、结构和设备造成的损伤取决于产生的超压大小和超压传递的速率（也称为冲量）。另外，这些损伤通常是由爆炸冲击引起的坠落，被爆炸冲击抛出并与坚硬表面碰撞，或被碎片撞击的结果。其简易指南如下：

- 爆炸压力为 0.25 bar 和 1 bar 时，其致死概率分别约为 1%和 50%[18]；
- 压力小于 0.25 bar 的爆炸可能将人员抛出并与坚硬表面发生碰撞，导致伤亡[18]；和
- 爆炸压力 0.3 bar 通常是对结构和工业设备产生损害的压力界限[18]。

船舶上气化的 LNG 发生爆炸可能导致人员死亡以及设备和船舶结构（包括船体）的损坏。

3.2.7 快速相变

在 LNG 释放时，由于来自周围空气、水/海、钢或地面的热量，LNG 将迅速沸腾。然而，这种快速且有时剧烈的沸腾不是快速相变（RPT）; RPT 是液体的爆炸性气化，即从液态到气态的接近瞬时的转变。这是一种比快速沸腾更剧烈的现象，并且它可以导致液体喷射和破坏性超压[19]。这种现象在钢铁行业中众所周知，其中熔融金属和水的意外接触可导致 RPT。

3.2.8 翻滚现象

低温储存的 LNG 吸收来自周围的热量缓慢地气化（即“蒸发”）并逐渐“泄漏”到储罐中。 理论上，与储罐壁接触的液体将被加热，密度降低并上升至顶部。 然后该顶层开始气化（即“蒸发”）从而增加了液体层的密度。远离舱壁的液体以较小的速率被加热，并因此在顶层下方形成了较小密度层。由于静压头，该层的饱和条件发生改变，因此尽管该层被加热但不会蒸发，而是保持在液体状态并变成“过热层”。 随着加热持续，该层密度逐渐下降；这是一种不稳定的状态，当该层的密度与顶层相近时，这两层迅速混合，并且处于过热状态的下层蒸发。这种迅速混合并蒸发的现象被称为翻滚现象，如果控制不当，翻滚现象可能导致储罐压力过大和 LNG 气体排放。

上述加热机制可以导致储罐内产生多个不同的温度层，称为分层现象。这是一种众所周知的现象，该现象可以通过排气、混合和温度控制来安全管控。

加注不同密度的 LNG 可以促进或直接导致上述现象的发生。

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18. 由于有许多不同来源的引用值不一致，也可使用冲量作为代替。此处引用的伤亡率是基于 Ref 16 和“确定危险物质对人员和物体造成的可能损害的方法”，CPR 16E，劳动监察局，荷兰。
19. Chamberlain, G. (2006). 大型 LNG 危害管理. 第 23 届世界天然气会议, 阿姆斯特丹.

No. 146 (cont)

3.3 参考文献

本附录中提供的信息和事实是众所周知的，并已记录在许多关于 LNG 的论文和报告中。然而，由于原始出处并不总是易于获得（或已知），因此本节中提供的信息通过参考以下内容进行了交叉检查：

1. Chamberlain, G. (2006). 大型 LNG 危害管理. 第 23 届世界天然气会议, 阿姆斯特丹.

2. 国际海事组织, 海上安全委员会. (2007). FSA – 液化天然气 (LNG) 运输船, 正式安全评估详细说明, MSC 83/INF.3.

3. Bull, D. 和 Strachan, D. (1992). 液化天然气安全研究.

4. Sheats, D. & Capers, M. (1999). LNG 储存中的密度分成, . Cold Facts, 15/2.

5. Bashiri, A. & Fatehnejad, L. (2006). LNG 储罐中翻滚现象的建模和模拟. 第 23 届世界天然气会议, 阿姆斯特丹.

还可以参考 ISGOTT（国际油轮与码头安全指南）出版物 (2009) – 关于 LNG 运输船货物围护系统火灾影响的报告.

No.
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(cont)

LNG 与燃油危害比较

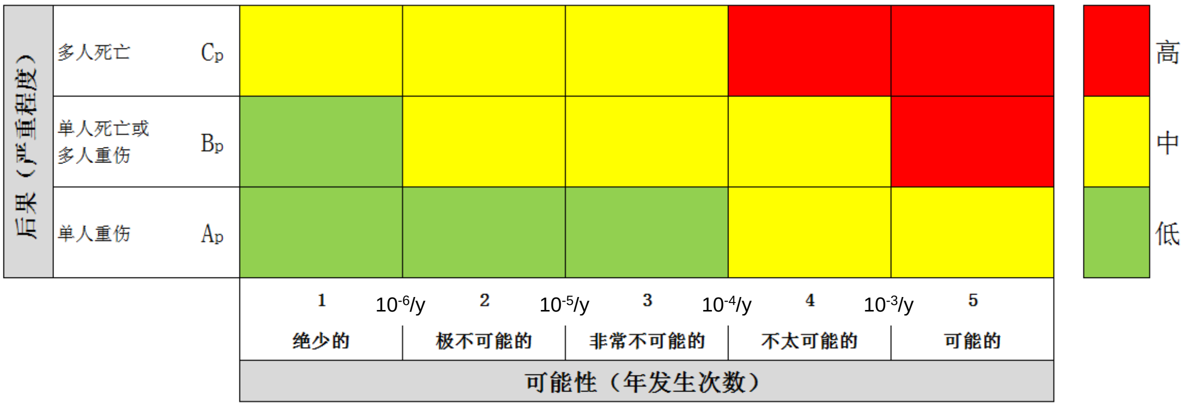
危害	LNG	燃油 [1]
1. 低温冻伤 液体与皮肤接触将引起低温冻伤并可能致死。呼吸气体可引起肺部灼伤并导致致命伤害。	✓	X
2. 低温冷脆 与液体接触时，设备/结构可能失效。	✓	X
3. 快速相变 (RPT) 释放到海上时会发生从液态到气态接近瞬时的“爆炸性”转变。这可能导致船体结构的损坏。	✓	X
4. 气体膨胀 液池迅速沸腾，并且随着气体加热膨胀，其体积将膨胀至液体体积的 600 倍。这可能导致设备损坏。	✓	X
5. 窒息 在密闭空间中，气体在空气中的置换和混合将降低氧气含量并且可能导致窒息。	✓	✓
6. 池火 液池上方的气体/蒸气可被点燃，引起池火。热辐射强度可能导致人员致命伤害，并使结构和关键设备失效。	✓	✓
7. 闪火 气体/蒸气可以从液池中扩散并被点燃，引发闪火。短时间且强力的热辐射可以引发二次火灾，并对处于闪火中的人员和关键设备造成致命伤害。火焰将很可能燃烧回液池，引发池火。	✓	X[2]
8. 爆炸 气体/蒸气可能扩散并聚集在密闭空间内，然后被点燃引发爆炸。爆炸可能导致人员收到致命伤害，结构和关键设备失效。爆炸将很可能燃烧回液池/气体源，从而引发池火或喷射火。	✓	X[2]
9. 翻滚现象 储存的液体可能分成，即不同的层可以具有不同的密度和温度。这可能引发“翻滚”现象，并导致大量气体/蒸气的产生，且这些气体必须被围护在储罐内。如果释放这些气体，将可能导致闪火或爆炸。	✓	X
10. 蒸发气 (BoG) LNG 持续沸腾，产生的蒸发气必须重新液化或燃烧。BOG 如释放将可能被点燃并引发喷射火（给定足够大的释放压力），闪火或爆炸。	✓	X

注意:
1. 燃油 – 重油 (HFO) (ISO 8217).
2. 如果燃油被喷射出并在空气中形成细小液体状的悬浮颗粒，此时点火将可能导致闪火或爆炸。

No. 146 (cont)

附录 4
风险矩阵

风险矩阵示例 – 船上人员



后果分类示例

A_P 单人重伤 – *长期残疾/健康影响*
B_P 单人死亡或多人重伤 – *单人死亡或多个个体长期遭受残疾/健康影响*
C_P 多人死亡 – *两人或两人以上死亡*

可能性分类示例

1. 绝少的 – *每年少于等于百万分之一次*
2. 极不可能的 – *每年百万分之一次至十万分之一次*
3. 非常不可能的 – *每年十万分之一次至万分之一次*
4. 不太可能的 – *每年万分之一次至千分之一次*
5. 可能的 – *每年千分之一次至百分之一次*

可能性分类可以与船舶的寿命有关。例如，假设一艘船舶的寿命为 25 年，则对于年发生可能性为百万分之一的场景（即等级 1， 绝少的），船舶在使用寿命中该场景出现的可能性为 1/40,000（即 $1/(10^{-6} \times 25)$）。

风险评级和风险标准示例

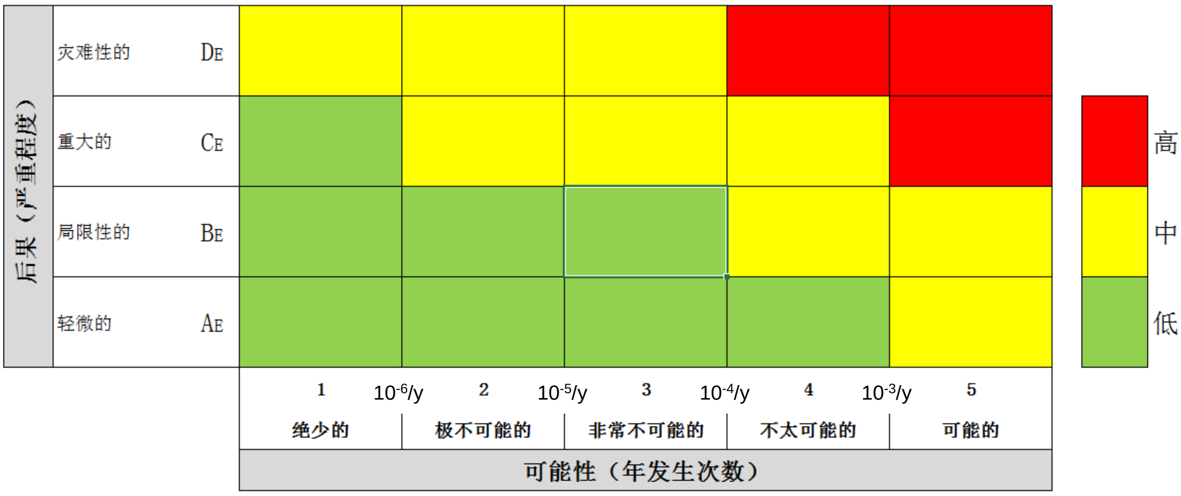
低风险 – A_P1, A_P2, A_P3 & B_P1
风险可以被接受为已"视需要减轻"。 考虑的实际性和成本效益，良好的做法是实施的减轻措施能够进一步地降低风险。

中等风险 – A_P4, A_P5, B_P2, B_P3, B_P4, C_P1, C_P2 & C_P3
风险是可以容许的并被视为已"视需要减轻"。这是假设所有合理可行的减轻措施已经实施。即附加或替代的减轻措施已经被识别并实施，除非判断这些措施是不切实际的或其执行成本与可减少的风险不成比例。

高风险 – B_P5, C_P4 & C_P5
风险是不可接受的且风险没有被"视需要减轻"。在操作前，附加或替代的减轻措施必须被识别且实施以降低风险，并且必须将风险降低至中等风险或低风险等级。

No. 146 (cont)

风险矩阵示例 – 环境



后果分类示例

A_E 轻微的 – *对附近敏感地区/物种的有限和可逆的损害*
B_E 局限性的 – *对附近敏感地区/物种的显着但可逆的损害*
C_E 重大的 – *对敏感地区/物种的广泛或持续的损害*
D_E 灾难性的 – 对*敏感地区/物种的不可逆的或长期的损害*

可能性分类示例

1. 绝少的 – *每年少于百万分之一次或更少*
2. 极不可能的 – *每年百万分之一次至十万分之一次*
3. 非常不可能的 – *每年十万分之一次至万分之一次*
4. 不太可能的 – *每年万分之一次至千分之一次*
5. 可能的 – *每年千分之一次至百分之一次*

可能性分类可以与船舶的寿命有关。例如，假设一艘船舶的寿命为 25 年，则对于年发生可能性为百万分之一的场景（即等级 1， 绝少的），船舶在使用寿命中该场景出现的可能性为 1/40,000（即 $1/(10^{-6} \times 25)$）。

风险评级和风险标准示例

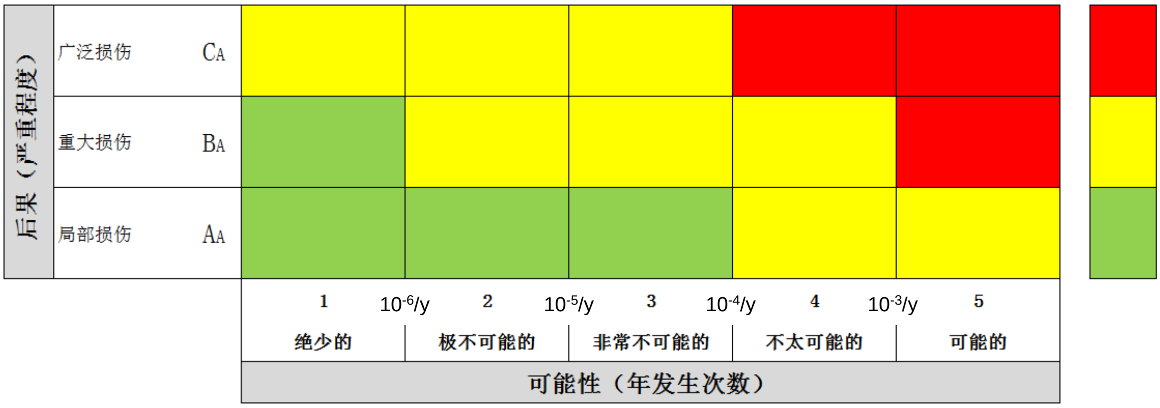
低风险 – A_E1, A_E2, A_E3, A_E4, B_E1, B_E2, B_E3 & C_E1
风险可以被接受为已“视需要减轻”。 考虑的实际性和成本效益，良好的做法是实施的减轻措施能够进一步地降低风险。

中等风险 – A_E5, B_E4, B_E5, C_E2, C_E3, C_E4, D_E1, D_E2 & D_E3
风险是可以容许的并被视为已“视需要减轻”。这是假设所有合理可行的减轻措施已经实施。即附加或替代的减轻措施已经被识别并实施，除非判断这些措施是不切实际的或其执行成本与可减少的风险不成比例。

高风险 – C_E5, D_E4 & D_E5
风险是不可接受的且风险没有被“视需要减轻”。在操作前，附加或替代的减轻措施必须被识别且实施以降低风险，并且必须将风险降低至中等风险或低风险等级。

No. 146 (cont)

风险矩阵示例 – 船舶资产（设备，处所和结构）



后果分类示例

A_A　局部损伤 – *事件使船舶停止运营超过 x 天*
B_A　重大损伤 – *事件使船舶停止运营超过 y 天*
C_A　广泛损伤 – *失去船舶，或事件使船舶停止运营超过 z 天*

可能性分类示例

1. 绝少的 – *每年少于百万分之一次或更少*
2. 极不可能的 – *每年百万分之一次至十万分之一次*
3. 非常不可能的 – *每年十万分之一次至万分之一次*
4. 不太可能的 – *每年万分之一次至千分之一次*
5. 可能的 – *每年千分之一次至百分之一次*

可能性分类可以与船舶的寿命有关。例如，假设一艘船舶的寿命为 25 年，则对于年发生可能性为百万分之一的场景（即等级 1， 绝少的），船舶在使用寿命中该场景出现的可能性为 1/40,000（即 $1/(10^{-6} \times 25)$）。

风险评级和风险标准示例

低风险 – A_A1, A_A2, A_A3 & B_A1
风险可以被接受为已“视需要减轻”。 考虑的实际性和成本效益，良好的做法是实施的减轻措施能够进一步地降低风险。

中等风险 – A_A4, A_A5, B_A2, B_A3, B_A4, C_A1, C_A2 & C_A3
风险是可以容许的并被视为已“视需要减轻”。这是假设所有合理可行的减轻措施已经实施。即附加或替代的减轻措施已经被识别并实施，除非判断这些措施是不切实际的或其执行成本与可减少的风险不成比例。

高风险 – B_A5, C_A4 & C_A5
风险是不可接受的且风险没有被“视需要减轻”。在操作前，附加或替代的减轻措施必须被识别且实施以降低风险，并且必须将风险降低至中等风险或低风险等级。

No. 146 (cont)

附录 5
释放的可能性

指示性概率分类

下表提供了以下指示性概率分类：(a) 指定设备项目失效并释放燃料[20]，和 (b) 发生碰撞和搁浅[21]。

可能性概率值根据来源、所做的假设和包含/排除的原因等有所不同。因此，重要的是参考原始数据来源以保证指示性概率分类适用于感兴趣的具体案例。

指示性概率值-可能性分类

1. 绝少的 – *每年少于百万分之一次或更少 (10^{-6}/y 或更少)*			
C 型独立液货舱	<1 x 10^{-6}		
2. 极不可能的– *每年百万分之一次至十万分之一次 (10^{-6}/y 至 10^{-5}/y)*			
泄漏孔径 ≥ 10 mm Ø	**50 mm 或更少 Ø**	**51-150 mm Ø**	**151-300 mm Ø**
管路/每米(m)	7 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}
法兰	4 x 10^{-6}	5 x 10^{-6}	7 x 10^{-6}
手动阀	---	7 x 10^{-6}	9 x 10^{-6}
3. 非常不可能的- *每年十万分之一次至万分之一次 (10^{-5}/y to 10^{-4}/y)*			
	50 mm 或更少 Ø	**51-150 mm Ø**	**151-300 mm Ø**
管路/每米(m)	8 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}
法兰	4 x 10^{-5}	5 x 10^{-5}	8 x 10^{-5}
手动阀	3 x 10^{-5}	5 x 10^{-5}	7 x 10^{-5}
4. 不太可能的 – *每年万分之一次至千分之一次 (10^{-4}/y 至 10^{-3}/y)*			
	50 mm 或更少 Ø	**51-150 mm Ø**	**151-300 mm Ø**
控制阀	3 x 10^{-4}	3 x 10^{-4}	3 x 10^{-4}
连接设备	3 x 10^{-4} 包括法兰		
工艺容器	7 x 10^{-4} 压力容器		
5. 可能的 – *每年千分之一次至百分之一次 (10^{-3}/y 至 10^{-2}/y)*			
		50-150 mm Ø	**>151 mm Ø**
热交换器 / 蒸发器 / 加热器		2 x 10^{-3}	2 x 10^{-3}
泵 (离心式或往复式)		5 x 10^{-3}	1 x 10^{-3}
客滚船	1 x 10^{-2} 碰撞 / 1 x 10^{-2} 搁浅		
游轮	5 x 10^{-3} 碰撞 / 1 x 10^{-2} 搁浅		
集装箱船	2 x 10^{-2} 碰撞 / 7 x 10^{-3} 搁浅 (参考失事/搁浅数据)		

概率值包括了所有的碰撞和搁浅。对于碰撞，这意味着当船舶是“撞击船舶”和“被撞击船舶”时，发生的所有碰撞。考虑到给定的船舶、航线和事件特性，感兴趣的具体案例的概率值可能比上表给出的值小。例如，假设一艘客滚船是“被撞击船舶”且撞击“严重”并因此释放燃料，则该事件的可能性概率值约为 5 x 10^{-4}（即等级 4“不太可能的”，假设“撞击/被撞击”的概率为 50/50，且撞击“严重”的可能性为 10%）。

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20. 指示值基于 (a) 和 (b) 并在 (c) 中概述：(a) Indicative values are based on (a) and (b) and summarised in (c): (a) 国际石油和天然气生产商协会. (2010 年 3 月 1 日). 风险评估资料目录 – 过程释放频率, 报告 No. 434 – 1; (b) 卫生安全局. (1992-2006). 烃类释放系统 (HCR). https://www.hse.gov.uk/hcr3/; (c) 海上 LNG 燃料 – LNG 释放的可能性. 海洋工程技术学报, Vol. 12, Issue 3, 2013 年 9 月.
21. 正式安全评估 (FSA): FSA 集装箱船, MSC 83/21/2 (表 3), 2007 年 7 月 3 日; FSA 游轮, MSC 85/17/1 (表 1), 2008 年 7 月 21 日; 和 FSA 客滚船, MSC 85/17/2 (表 1), 2008 年 7 月 21 日.

No. 146 (cont)

附录 6
减轻措施

减轻措施示例

工程减轻措施
防止机械冲击损坏
防振动/ 振动监控
防风、波浪和恶劣天气
泄压，通风
增加分隔或增加物理防护免受碰撞/搁浅
次围护（例如双壁管）
优先考虑焊接连接而不是法兰连接
装有警报的自动关闭门
分隔舱壁/ 围堰
承滴盘容量，液体探测
水雾防护
保护结构免受于低温以及压力蒸气/气体
独立舱底水系统
火灾和气体探测、监测、声光报警以及停机
压力和温度探测、监测、声光报警以及停机
液位探测
强制/自然通风 – 气闸
点火源最小化 – 防爆电气设备
消防灭火和冷却设备 – 泡沫、水喷淋
挡火闸
处所分隔
通道布置
物理屏壁
系泊张力监测/报警
支撑结构应变监测
缓冲/ 溢流舱 – 燃料回收
符合 IEC 61508 的独立安全防护装置
雷达监测
工作介质 – 液位/ 气体探测、报警和关闭
阻火器
程序减轻措施
增加检查（和维护）的频率
降低零件更换的频率
对低闪点燃料进行特定培训
限制进入
监控
注意： 1. 上述减轻措施大部分是通用的且没有特定顺序。在考虑减轻措施时，可将其列为简单的备忘录。 2. 在 IGF 规则中, 降低可能性的措施和减轻后果的措施均可被理解为减轻措施 (即他们均能减轻风险)。 为了与 IGF 规则中保持一致,，本文中保留了这一理解. 可以认识到在许多其他行业中， 通常使用术语“预防措施”和“缓解措施”，前者降低

No. 146 (cont)

风险的可能性而后者减轻风险的后果。预防和减轻措施通常被称为“保障措施”或“屏障”。

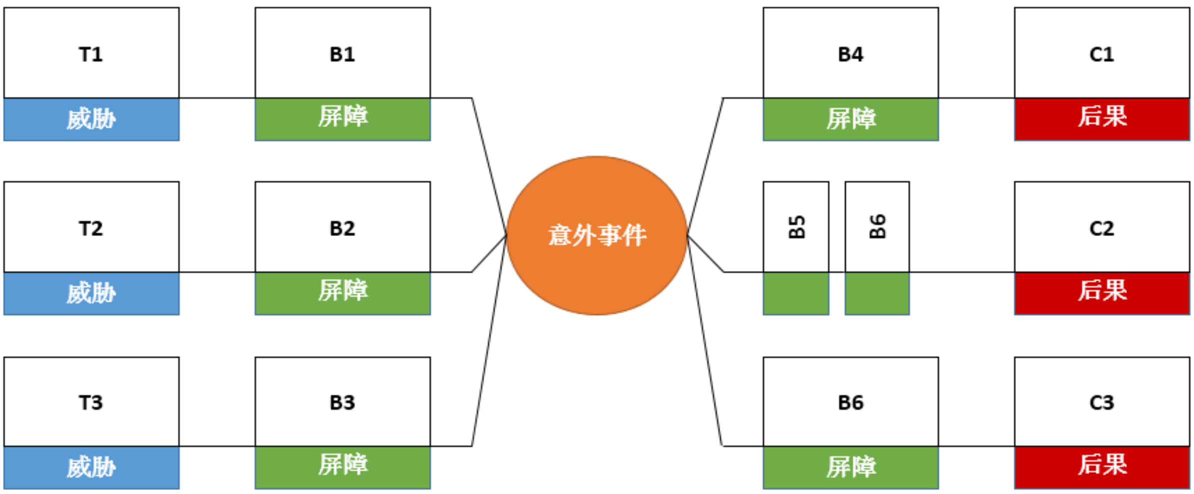
No. 146
(cont)

附录 7
因果图

说明或绘制因果路径的一种现有方法称为 Bowtie。这种方法有多种变化和不同的术语，但其本质上都是形象化地展示：意外事件发生的威胁或原因；防止意外事件发生的预防措施或减轻措施；和减轻后果的屏障。

Bowtie 示例

威胁 – *导致意外事件发生的潜在原因。*
屏障 – *能潜在地防止意外事件发生或减轻其后果的缓解措施。*
意外事件 – *需要避免的情况，例如燃料释放或船舶推力丧失。*
后果 – *威胁引发的意外事件没有被屏障缓解而造成的后果。*



关于“减轻措施”（即屏障），在意外事件发生之前的那些措施通常被称为预防屏障或预防措施。

No. 146 (cont)

附录 8
报告目录

报告目录示例

执行摘要
评估内容、主要结果和结论的概述。
1. 引言
简要说明评估目的和有关各方。
2. 目标和范围
主要目标是，例如，证明安全风险是或者可以被接受/容许并被船级社批准。范围是，例如，限于设计/布置、特定环境/位置和预期操作模式。
3. 描述
有关预期操作和工艺条件的设计和布置的简单解释。
4. 方法
风险评估技术/方法的概述。这包括如何将总体设计划分为不同部分进行评估，危险识别如何进行，风险标准如何选取，以及风险评级和记录的机制。此外，需要一个研讨会的实际时间表，表上说明了每个部分花费的时间。
5. 团队
协调人和学科领域专家的姓名、职称、相关资质、专业知识和经验。这些信息可以与研讨会的出席记录一同记录在表格中。如果这些信息特别多并且会转移对方法和结果的注意，则可以将这些信息作为附录包括在内。
6. 结果
讨论主要结果和问题。
7. 结论
简要判断风险是否已“视需要减轻”。
8. 采取行动
附加/替代保护措施的清单，包括负责人和预计完成的日期。.
附录
A. 研讨会 （如研讨会上的记录，包括引导词和引导短语，即提示性语言）。
B. 图纸、工艺信息和参考文件（包括报告范围 ToR）

文档结束