preFLASH - Preliminary study of protection against fire in low-flashpoint fuel

Per Blomqvist, Franz Evegren, Ola Willstrand and Magnus Arvidson
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Abstract

Stricter emission requirements imply that ships in the SECA area (Sulfur Emission Control Area) will increasingly operate on alternative fuels with a low flashpoint. The IMO regulation for low flash-point fuels, the so-called IGF code was formally adopted in June 2015. At this stage it includes regulations for ships with LNG installations, whilst regulations applicable to methanol are still under development. The code covers many technical risks and describes how safety systems should be designed for low flashpoint fuels, with focus on LNG. However, regarding active fire protection systems, i.e. detection and extinguishing systems, there are no instructions to assure validated performance with alternative fuels.

The proFLASH project aims to develop technical guidelines for detection and extinguishing systems, to ensure that they are designed with adequate protection against fire when low-flashpoint fuels are involved; in particular methanol and LNG. The project was divided in two phases. Phase 1, which is reported here, is a preliminary study that includes a thorough review of the properties of LNG and methanol, and a theoretical investigation of how these can affect the effectiveness and efficiency of detection and extinguishing systems. A literature study was also made of relevant regulations and class rules and conclusions were made regarding the need for fire testing. Phase 2 of the project will take on some of these experiments, starting in 2016 and will be reported thereafter.

The study of the preliminary regulations and rules for methanol installations shows that these requirements to a large degree are formulated in a traditional way. Even though similar means as for LNG are proposed to be taken to avoid making methanol available and to prevent ignition and fire, it is still required to offensively manage a methanol fire. This is not the case for LNG in the current IGF code, where avoiding release and fire spread to tanks etc. seem to be the only protective measures against fire. It is further concluded that LNG fire mitigation has some tradition and that the use of LNG as a bunker fuel has benefited from this work. The requirements for methanol installations found in the regulations under development from IMO and from classification societies vary; likely due to lack of knowledge in how firefighting of methanol is best accomplished. This preliminary study recommends a testing programme focused on methanol, which needs to include both fundamental studies to characterize the fuel and comparative large-scale tests with extinguishing systems for verification.

Key words: low flashpoint, methanol, LNG, detection, extinguishment

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Contents

Abstract 3

Contents 4

Acknowledgments 6

Sammanfattning (in Swedish) 7

1 Introduction 8

2 Fuel properties 10
   2.1 Introduction 10
   2.2 General properties 10
   2.3 Ignition and flammability 12
   2.4 Burning behaviour 15
   2.4.1 Methanol 15
   2.4.2 LNG 17

3 Regulatory framework 20
   3.1 Background to IMO regulations 20
   3.2 Regulations and rules for LNG 21
      3.2.1 Preamble and general requirements of the IGF Code 21
      3.2.2 IGF Code Part A-1 for LNG 21
      3.2.3 Class rules for LNG 22
   3.3 Regulations and rules for methanol 23
      3.3.1 Draft guidelines for methanol 23
      3.3.2 Provisional Class rules for methanol 24
   3.4 Summary of regulation investigations 25

4 Gas and fire detection 28
   4.1 Requirements for detection systems 28
      4.1.1 Requirements for point fire detection and alarm systems 28
      4.1.2 Requirements for sample extraction smoke detection 29
   4.2 Considerations for low-flashpoint fuels 30
      4.2.1 Detection of LNG 30
      4.2.2 Detection of methanol 32

5 Fixed fire extinguishment 35
   5.1 General requirements in SOLAS 35
   5.2 Gas fire extinguishment of methanol 36
   5.3 Water-based fire extinguishment of methanol 37
      5.3.1 Oxygen dispersion and flame cooling 38
      5.3.2 Surface and flame cooling 38
   5.3.3 Dilution 40
      5.3.4 Foam fire extinguishment of methanol 41
      5.3.5 Large-scale tests with a water mist fire-extinguishing system 41
      5.3.6 Conclusions on water-based extinguishment of methanol 43
   5.4 Fire extinguishment of LNG 43
      5.4.1 Fire mitigation strategies 44
      5.4.2 Water-spray application 45
      5.4.3 Dry chemical powder fire-extinguishing system 45
      5.4.4 High expansion foam 45
5.4.5 Foam glass
5.4.6 Conclusions on fire extinguishment of LNG

6 Conclusions on hazards and implications for detection and extinguishment

6.1 Hazards from LFFs
6.2 Need for testing and verification
6.2.1 Gas and fire detection
6.2.2 Fire extinguishment

7 References

Appendix A IMO tests for fixed fire extinguishing systems

References
Acknowledgments

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We also would like to acknowledge the in-kind work done by the project partners, which included the participation on a HazId-meeting and a seminar. The project partners represented were: the Swedish Transport Agency, Lloyd’s Register, Stena, Marinvest, ScandiNAOS, Tyco, Consilium and Ultrafog.
Sammanfattning (in Swedish)

Skärpta utsläppsgrans gör att fartyg kring Sveriges kuster i allt större utsträckning kommer att operera på alternativa bränslen med låg flampunkt. För att säkerheten på fartygen därmed inte ska försämras krävs ökad kunskap om brandriskerna som introduceras och regler för hur brandskyddet ska utformas anpassat till de nya bränslen.


Efter ett intensivt utvecklingsarbete inom IMO med regler för alternativa bränslen med låg flampunkt, antogs den s.k. IGF-koden av MSC i juni 2015. Än så länge fokuserar koden på LNG, medan regler för metanol arbetas fram under koordinering av Sverige. IGF-koden täcker i nuläget många tekniska risker och beskriver hur säkerhetssystem ska utformas med hänsyn till bränslen med låg flampunkt i allmänhet och till LNG i synnerhet. När det kommer till hur aktiva brandskyddssystem (detektion och släcksystem) bör utformas så saknas dock instruktioner för att garantera validerad effektivitet med alternativa bränslen. Bristen på sådana instruktioner kan leda till att system installeras med ineffektiv och otillräcklig prestanda, vilket hotar säkerheten på fartyg som i stor utsträckning trafikerar svenska farvatten med svenska sjömän och passagerare.

Pro-FLASH projektet syftar till att höja kompetensen och påverka regelverk gällande brandskydd för nya lågflampunktbränslen så att brandskyddet kan garantera på fartyg som i stor utsträckning trafikerar svenska farvatten. Projektet är uppdelat i två faser. Fas 1 av projektet (pre-FLASH), vilket rapporteras här, är en förstudie som startade i maj 2015. Förstudien innefattar en grundlig översyn av egenskaper för LNG och metanol och en teoretisk utredning av hur dessa kan påverka effektiviteten för detektion- och släcksystem. En litteraturstudie görs även av relevanta föreskrifter och klassregler. Fas 2 är projektets experimentella del vilken är planerad att genomföras under 2016.

Deltagare i fas 1 innefattade: forskningsinstitut (SP), flaggstat (Transportstyrelsen), klassificeringssällskap (Loyd's Register), redare (Stena, Marininvest), fartygskonstruktör (ScandiNAOS) och leverantörer av släck- och detektionssystem (Tyco, Ultrafog, Consilium).

SP Fire Research har lett förstudien och skrivit denna rapport som innehåller:

- egenskaper för LNG och metanol;
- brandfaror som introduceras genom användning av de nya bränslen;
- begränsningar för traditionella brandskyddssystem (detektion och fasta släcksystem) för att hantera dessa brandfaror; och
- föreslag på försök och metoder för att verifiera tilltråcklig prestanda för detektions- och släcksystem.
1 Introduction

Requirements on sulphur content in bunker fuel are regulated by the MARPOL Convention (MARPOL - International Convention for the Prevention of Pollution from Ships). The 1 January 2015, the requirements for bunker fuels were made stricter for ships operating in a so-called SECA area (Sulphur Emission Control Area) covering the Baltic Sea, North Sea and English Channel. With the new requirements a maximum of only 0.10 weight percent sulphur is allowed in the fuel. Several more areas may become SECA areas in the future and there are reduction plans prepared both for designated SECA areas and for areas which are not. Table 1 shows the reduction plan for the two types of areas.

Table 1 Reduction plan for sulphur content in bunker fuel.

<table>
<thead>
<tr>
<th>Effective date</th>
<th>SECA</th>
<th>Other areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1 July 2010</td>
<td>1.50%</td>
<td>4.5%</td>
</tr>
<tr>
<td>From 1 July 2010</td>
<td>1.00%</td>
<td>- “ -</td>
</tr>
<tr>
<td>From 1 January 2012</td>
<td>- “ -</td>
<td>3.5%</td>
</tr>
<tr>
<td>From 1 January 2015</td>
<td>0.10%</td>
<td>- “ -</td>
</tr>
<tr>
<td>From 1 January 2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or 2025*</td>
<td>- “ -</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

* To be decided in 2018.

The practical result of the sulphur reduction plan was that the traditionally used heavy fuel oil (HFO) was substituted with marine gas oil (MGO) in the SECA areas in 2010. In other areas HFO can still be used until 2020, or longer. In 2015, when the requirements became stricter in the SECA areas, low sulphur alternatives had to be introduced. The most relevant options to meet the requirements currently are to either equip the vessel with an emission cleaning system (scrubber) or to use low-sulphur fuel. The latter can be accomplished in several ways, e.g. by operating on more expensive low-sulphur diesel (MDO) or by converting to operation on new bunker fuels, such as methanol or LNG. These fuels are interesting in many respects, not least because they to some extent can be produced from bio-materials and thus can reduce the contribution to the greenhouse effect. However, the properties of the fuels in several ways differ from those of traditional ship fuels. This introduces new risks. One important difference is the fuels’ low flashpoints, which can increase the fire risk in case of a fuel leakage. Their low flashpoints violate SOLAS regulation 4.2.1.1, which states that the flashpoint of an engine fuel shall be >60°C. Such a fuel therefore has to be treated with alternative fire safety design and arrangements in line with SOLAS II-2/17.

In order for low-flashpoint fuels (LFFs) to be handled in a harmonized and safe way, the IMO is currently developing applicable regulations, the so-called IGF Code. This primary work is done through a correspondence group (currently led by Sweden) under the sub-committee Carriage of Cargoes and Containers (CCC). After intense development within the IMO the IGF code was formally adopted by the Maritime Safety Committee (MSC) in June 2015. So far the code includes regulations for LNG whilst regulations applicable to methanol are being developed under coordination by Sweden. The current IGF Code covers many technological risks and describes how safety systems should be designed. However, the instructions given for the design of active fire protection systems (detection and extinguishing systems) are sparse. Insufficient such instructions may lead to systems installed with inadequate performance, which threatens the safety on vessels operating on Swedish and international waters.
The proFLASH project aims to develop technical guidelines for detection and extinguishing systems, to ensure that they are designed with adequate protection against fire when low-flashpoint fuels are involved; in particular methanol and LNG. The project focuses on these fuels since their use is expected to become widespread and because they well represent the challenges of new alternative fuels for active fire protection systems. Furthermore, the project will provide recommendations on how rules should be developed to manage the risks that these fuels introduce. Suitable ways to verify the effectiveness of active systems are lacking and the project will therefore also propose methods and criteria for testing the performance of detection and extinguishing systems.

The project was divided in two phases, where this report documents **Phase 1, called preFLASH.** It consists in a preliminary study for the project which was initiated in May 2015. The study includes a review of relevant properties of LNG and methanol, and a theoretical investigation of how these can affect the effectiveness and efficiency of detection and extinguishing systems. A literature study was also made of relevant regulations and class rules. The aim for phase 1 was to identify:

- hazards that are introduced by use of the new fuels;
- limitations of traditional fire protection systems to manage these hazards;
- potential systems solutions to manage the introduced hazards; and
- proposals of methods to verify sufficient performance of detection and extinguishing systems.

Participants in phase 1 include: research institute (SP), flag state (the Swedish Transport Agency), classification society (Lloyd’s Register), ship owners (Stena, Marinvest), ship designer (ScandiNAOS) and system suppliers (Tyco, Ultrafog and Consilium). **Phase 2** is a proposed experimental part of the project, to be carried out during 2016 if funding is approved. Relevant large-scale fire tests will be conducted to verify system solutions and validate test methods proposed in phase 1.
2 Fuel properties

Properties relevant to fire safety are given below for methanol and liquefied natural gas (LNG). Section 2.1 is an introduction on why alternative fuels are necessary. General fuel properties and flammability properties determined from standardised laboratory tests are presented in section 2.2 and section 2.3. Typical burning behaviour of fires with these fuels, such as heat release rate (HRR) and soot production are presented and discussed in section 2.4. The special hazards associated with these alternative fuels are identified and discussed in section 6.

2.1 Introduction

The properties of alternative bunker fuels differ in many ways from HFO. MGO, which has been the most common alternative, is a refined petroleum distillate with reduced sulphur content. It can be used as a conventional alternative to HFO since it achieves the SOLAS requirement for fuels to have a flashpoint over 60°C. Pre-heating of MGO is not necessary before combustion, which is the case for HFO. The same applies to a new low sulphur version of the fuel (LSMGO) which is now also available, which achieves both the flashpoint requirement and the current sulphur requirement in SECA areas. The main disadvantage of LSMGO would be the cost. There are also recently different low-sulphur “hybrid” fuels available that have many properties in common with HFO [1]. These fuels do not require significant modifications of the ships fuel system and for example require pre-heating, just like HFO. However, also here the cost is a limiting factor for the use of this type of fuel.

Methanol and LNG are two major alternative fuels that both are inherently free from sulphur and economically viable options. These fuels both have flash points below 60°C, but have very different properties compared to HFO and MGO. The differing fuel properties make it clear that fuel handling systems and safety considerations have to be adapted to each fuel individually. In the following sections are given some typical properties of methanol and LNG in comparison with properties of HFO and MGO.

2.2 General properties

Typical physical properties of methanol and LNG are given in Table 2 and compared with the properties of HFO (residual oil fuels) and MGO (distillate oil fuels). There are different types of both HFO and MGO fuels available on the market, as specified in ISO 8217 [2], which differ in e.g. viscosity and sulphur content.

The physical data for methanol is easier to specify, as this fuel contains a single chemical substance with a low degree of contaminants. LNG varies to a limited extent in composition depending on the source of the gas, and characteristic physical properties are given here.
Table 2  General properties.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Heavy Fuel Oil (HFO)</th>
<th>Marine Gas Oil (MGO)</th>
<th>Methanol</th>
<th>Liquid Natural Gas (LNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition</strong></td>
<td>Residual from distillation, chain length of 20-70</td>
<td>Petroleum distillate, chain length of 10-20</td>
<td>CH₃OH</td>
<td></td>
</tr>
<tr>
<td>CH₄ (88-97 %)</td>
<td>other major components are C₇H₁₈, C₈H₁₈ and C₉H₁₈</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td>Highly viscose liquid, preheated before combustion</td>
<td>Liquid</td>
<td>Liquid</td>
<td>Stored as non-compressed liquid (-162 °C), gasified before combustion</td>
</tr>
<tr>
<td><strong>Sulphur content</strong> (wt-%)</td>
<td>&lt; 3.5 - &lt; 4.5 for HFO</td>
<td>&lt; 1.0 - &lt; 1.5 for MGO</td>
<td>&lt; 0.1 for LSMGO</td>
<td>&lt;&lt;0.1</td>
</tr>
<tr>
<td><strong>Viscosity</strong> (mm²/s)</td>
<td>30 - 700, at 50 °C</td>
<td>1.4 - 6.0, at 40 °C</td>
<td>0.59 - 0.74 at 20 °C</td>
<td>-</td>
</tr>
<tr>
<td><strong>Density</strong> (Kg/m³)</td>
<td>960 - 1010 for HFO (at 15 °C)</td>
<td>&lt;890 for MGO and LSMGO (at 15 °C)</td>
<td>792 (at 15 °C)</td>
<td>431 - 464 (liquid density at boiling point)</td>
</tr>
<tr>
<td><strong>Boiling point</strong> (°C)</td>
<td>150 - 600 for HFO</td>
<td>149 - 366 for MGO (at 15 °C)</td>
<td>65 (at 15 °C)</td>
<td>~ -160</td>
</tr>
<tr>
<td><strong>Vapour pressure</strong> (kPa) at 20 °C</td>
<td>&lt;0.1</td>
<td>~5×10⁻²</td>
<td>12 - 14</td>
<td>~1.5 (at boiling point) ~0.6 (at 20 °C)</td>
</tr>
<tr>
<td><strong>Vapour density</strong> (air = 1)</td>
<td>&gt;5</td>
<td>&gt;3</td>
<td>1.1 (at boiling point)</td>
<td>~0.6 (at 20 °C)</td>
</tr>
<tr>
<td><strong>Water solubility</strong> (mg/L)</td>
<td>&lt;1 to 6</td>
<td>Negligible</td>
<td>100 v/v % soluble</td>
<td>No</td>
</tr>
<tr>
<td><strong>Energy content, higher calorific value</strong> (MJ/kg)</td>
<td>~43</td>
<td>~44</td>
<td>23</td>
<td>~50</td>
</tr>
<tr>
<td><strong>Energy density</strong> (MJ/L)</td>
<td>~43</td>
<td>~39</td>
<td>18</td>
<td>~22 (liquid)</td>
</tr>
</tbody>
</table>

*a* ISO 8217 [2].

*b* Data specification for Shell Marine Gasoil (LSMGO).

*c* Data specification for no. 2 fuel oil (MSDS Code 001847).

*d* Data specification for Shell Marine Fuel Oil.

*e* August 2015: http://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html


*g* If nothing else specified, data is from Woodward and Pitblado [3].

*h* EPA [4].
2.3 Ignition and flammability

Flammability and explosion properties are given in Table 3. It is clear that the data for HFO and MGO would not be fixed values as these fuel designations contain different categories of fuel products as described above.

The data presented are determined using standardised test methods. The data is dependent on the physical constraints of the specific test method and it is useful to have some knowledge of the test method when interpreting data. Below are the test methods for Flashpoint, Auto ignition temperature and Flammability limits presented in detail. The test standards for explosion properties are cited below but not discussed in detail.

Table 3 Flammability and explosion properties.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Heavy Fuel Oil (HFO)</th>
<th>Marine Gas Oil (MGO)</th>
<th>Methanol</th>
<th>Liquid Natural Gas (LNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flashpoint (°C)</td>
<td>&gt;60 (65 – 80)</td>
<td>&gt;60 (60 – 75)</td>
<td>10 – 12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-188&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Auto ignition temperature (°C)</td>
<td>&gt;400</td>
<td>&gt;250</td>
<td>440&lt;sup&gt;d&lt;/sup&gt;, 463&lt;sup&gt;b&lt;/sup&gt;</td>
<td>540&lt;sup&gt;e&lt;/sup&gt;, 595&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Flammability limits (vol.-%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Typical 1.5 – 6.0</td>
<td>Typical 1.0 – 6.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.0 – 36&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.4 – 14.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Flammability temperature limits (°C)</td>
<td>-</td>
<td>64 – 150 (diesel)</td>
<td>11 – 41</td>
<td>-</td>
</tr>
<tr>
<td>Explosion group</td>
<td>IIA T3&lt;sup&gt;f&lt;/sup&gt; (fuel oil)</td>
<td>IIA T3&lt;sup&gt;f&lt;/sup&gt; (diesel fuel)</td>
<td>IIA T2&lt;sup&gt;g&lt;/sup&gt; IIA T1&lt;sup&gt;f&lt;/sup&gt;</td>
<td>IIA T1&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Minimal ignition energy, MIE (MJ)</td>
<td>N.A.</td>
<td>N.A. 0.24&lt;sup&gt;e&lt;/sup&gt; (heptane)</td>
<td>0.14&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.28&lt;sup&gt;e&lt;/sup&gt; (methane)</td>
</tr>
</tbody>
</table>

<sup>a</sup> The data on flammability limits is here taken as equal to explosion limits.
<sup>f</sup> Powermite, Classification of electrical apparatus into explosion groups and temperature classes, September 2015: http://www.powermite.co.za/download-catalogue/plugs-sockets/classification-explosion-groups.pdf
<sup>g</sup> Stahl, Basics of explosion protection, September 2015, http://www.controlglobal.com/assets/Media/MediaManager/article_135_rstahl_explosionprotection.pdf
<sup>h</sup> Woodward and Pitblado [3].

The **Flashpoint** is the lowest temperature at which the fuel/air mixture above a fuel surface can be ignited. A more specific definition of the flashpoint parameter is that this is the lowest temperature at which the application of an ignition source causes the vapour of a test portion to ignite and the flame to propagate across the surface of the liquid under the specified conditions of the test. The flashpoint is thus a measure of the propensity of piloted ignition.

There are a number of different test methods available for the determination of flashpoint. There are two main groups of methods, the open cup type and the close cup type. The difference in measured flashpoint value is significant between methods and it has to be
stressed that the measured flashpoint value is representative only for a particular test and further cannot be directly transferred to real conditions. The Pensky-Martens closed cup method is the method adopted for marine fuels and is described in ISO 2719:2002 [5]. More details of test methods for flashpoint can be found in [6] and information specifically for the determination of flashpoint for marine fuels in [7].

The classification of flammable liquids from UN [8] is based on flashpoint determination and is helpful in categorizing the flammability of different substances. Different national and international test methods are allowed for the classification [9]. Substances are listed as flammable if their flashpoint is not more than 60 °C in a closed-cup test or not more than 65.6 °C in an open-cup test. The classification scheme and some examples on the classification of different chemicals and fuels are given in Table 4.

**Table 4** UN categories for flammable liquids with examples.

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteriaa</th>
<th>Hazard statement</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flashpoint &lt; 23 °C and initial boiling point ≤ 35 °C</td>
<td>Extremely flammable</td>
<td>Ethyl ether, pentane</td>
</tr>
<tr>
<td>2</td>
<td>Flashpoint &lt; 23 °C and initial boiling point &gt; 35 °C</td>
<td>Highly flammable</td>
<td>Acetone, gasoline</td>
</tr>
<tr>
<td>3</td>
<td>Flashpoint ≥ 23 °C and ≤ 60 °C</td>
<td>Flammable</td>
<td>Kerosene, diesel fuel</td>
</tr>
<tr>
<td>4</td>
<td>Flashpoint &gt; 60 °C and ≤ 93 °C</td>
<td>Combustible</td>
<td>Pine oil, fuel oil no.1</td>
</tr>
</tbody>
</table>

a The flashpoint criteria refers to the results of a closed-cup test.

The **Auto ignition temperature** is a test parameter for non-piloted ignition of a liquid or a gaseous fuel. The definition of auto ignition temperature in the test standard EN 14522 [10] is that this is “the lowest temperature (of a hot surface) at which under specified conditions an ignition of a flammable gas or flammable vapour occurs”. In EN 14522 the amount of substance and the temperature of the test vessel, which is filled with air or air/inert gas, are varied to find the lowest temperature (of the hot surface of the test vessel) that causes ignition. The auto ignition temperature thus represents a scenario where air with a certain concentration of fuel vapour comes in contact with a hot surface, which heats the adjacent gas sufficiently for spontaneous ignition.

For combustion to take place, fuel vapour/air of a certain concentration range is possible. This range is defined by the **Flammability limits**, which differs significantly for different fuels. Below the lower flammability limit (LFL), sustained combustion will not take place as the fuel air mixture is too lean. Above the upper flammability limit (UFL) the mixture is too rich and the combustion is quenched. The flammability limits define the concentration range, at defined temperature and pressure, where a dispersed combustible substance can burn. Flammability limits are often also referred to as, and equalled to, **Explosion limits**. The accepted test standard for flammability limits is ASTM E681-09 [11] and the standard for explosion limits is EN 1839 [12]. It has been showed that the results on flammability limits by ASTM E681-09 are quite similar to the results on explosion limits by EN 1839 [13].

An illustration of the influence of the temperature on the flammability of the vapour/air mixture above a fuel surface in a semi-closed vessel is given in Figure 1. Below a certain temperature the saturated vapour/air mixture is below the LFL and combustion is not possible. Above a certain temperature the saturated vapour/air mixture is such that it is above LEL and combustion is possible. At a certain higher temperature, the saturated vapour/air mixture has such a concentration that UFL is reached and combustion is again not possible. The concept of flammability limits, between which a vapour/air mixture can be ignited, and the auto ignition temperature are also illustrated in Figure 2.
Figure 1   Illustration of how the flammability of the vapour in a semi-closed vessel is influenced by the temperature.

Figure 2   General outline of the effect of temperature on the flammability limits of a combustible vapour in air at a constant initial pressure, reproduced from [14].

With regards to explosion properties, gases and vapours are classified into different Explosion groups, defined in EN 60079-0 [15]. Classification criteria are the parameters Maximum Experimental Safe Gap (MESG) and Minimum Ignition Current (MIC). These parameters are determined according to IEC 60 079-1A [16], respective IEC 60079-12.
The classification system divides gases in explosion groups IIA, IIB and IIC. The dangerousness of the gases increases from explosion group IIA to IIC.

The explosion group class is followed by a temperature class. This class is based on the ignition temperature of a flammable gas or liquid, which is the lowest temperature of a heated surface at which the gas/air or vapour/air mixture ignites and is determined by the test standard IEC 60079-4 [18]. Ignition temperatures of the flammable substance associated with the temperature classes includes T1-T5 where T1 >450°C, T2 215-450°C, T3 160-300°C, T4 120-200°C, T5 100-135°C and T6 85-100°C.

The Minimal ignition energy (MIE) is determined by ASTM E582 [19]. Tests are performed on gas mixtures in a one litre container using capacitance sparks and flanged electrodes.

### 2.4 Burning behaviour

The burning behaviour of methanol and LNG is in many aspects different from those of traditional marine fuels. Further is the burning behaviour very different between these two fuels, as methanol is a liquid at room temperature and LNG is in gas phase.

The characterization of burning behaviour is for the application of marine fuels appropriate to be divided in:

- general burning behaviour; and
- pool fires.

For release of gaseous fuel, the timing of ignition is important for the consequences. Early ignition will tend to give rise to a local spray/jet fire, whilst delayed ignition can cause an explosion or flash fire.

The general burning behaviour and these specific types of fires are discussed for methanol and LNG below.

#### 2.4.1 Methanol

Methanol is combusted efficiently in a fire without the production of visible smoke. This means that the yellow colour from the incandescence of small soot particles in a diffusive flame is not present; neither are black non-combusted soot particles. A methanol flame is weakly light blue in colour and in many situations in essence invisible.

The absence of soot production has an influence on the transport mechanisms of heat from the flame, where radiative heat transfer \( H_R \) is less important compared to convective heat transfer \( H_C \) due to the absence of soot radiation. A comparison of the transport mechanisms of heat for different liquid fuels was presented in [20]. It for example shows that heptane has a total heat release \( \text{H}_\text{tot} \) of 41.4 kJ/g where \( H_C = 26.2 \text{ kJ/g} \) and \( H_R = 15.2 \text{ kJ/g} \) (36 %), whilst methanol has \( \text{H}_\text{tot} \) of 19.0 kJ/g, where \( H_C = 16.1 \text{ kJ/g} \) and \( H_R = 2.9 \text{ kJ/g} \) (15 %).

The low \( H_\text{tot} \) and the low radiative feedback for methanol have important influences on the mass burning rate in pool fires. McGrattan et al. [21] propose a mass burning rate of 0.017 kg/m\(^2\)/s for methanol in pool fires, which can be compared to 0.035 kg/m\(^2\)/s for no.2 diesel fuel. The low mass burning rate of methanol, in the combination with the low \( H_\text{tot} \), results in a prediction of a heat release per unit area of only 340 kW/m\(^2\), derived with the simplified prediction model proposed. The correspondent prediction for no. 2 diesel fuel is 1400 kW/m\(^2\).
However, it is also important to consider that the mass burning rate (per area unit) is in fact influenced by the size of the liquid pool and increases with pool size according to Babrauskas [22]. Babrauskas proposes to use a mass burning rate of 0.015 kg/m$^2$/s for pool fires with a diameter ($D$) < 0.6 m, 0.022 kg/m$^2$/s for 0.6 m < $D$ < 3.0 m, and 0.029 for pool fires > 3.0 m. The numbers given are proposed to be approximations valid both for methanol and ethanol. The mass burning rate for large alcohol fuel fires is thus significantly larger compared to that from small fires.

The burning rate (liquid regression rate) of methanol pool fires was experimentally determined in a series of tests with different pool areas up to 50 m$^2$ in an early Swedish study [23]. It was seen that the liquid burning rate increased with pool diameter to converge at a velocity of ~2 mm/min. This was considerably lower than the rate of ~6 mm/min determined for M15 (15 % methanol in petrol) which was also included in the test series.

![Figure 3](image-url)  
**Figure 3** Thermal radiation spectra incident on a 2 m fuel pool at a radius of 38 cm for different fuels (reproduced from [24]).

Suo-Anttila et al. [24] have characterised the radiation spectra for pool fires (2 m radius). In their test series ethanol was included, which shares the property of negligible soot production with methanol. As can be seen from Figure 3, the spectrum for ethanol differs considerably from those of hydrocarbon fuels such as heptane and JP-fuel. The absorption from soot in the spectral range below ~2.5 microns is not present, which makes the total radiation intensity much lower for ethanol. They further studied the absorption of the liquid fuel for the incoming radiation. This showed that ethanol was the most absorbing of the fuels studied; over 90 % of the energy was absorbed in the first 3 mm of the ethanol fuel bed. Heptane was the most transmissive, with about 65 % of the energy absorbed.

Alger et al. conducted fire tests with 3 m diameter pools of methanol and JP-5 fuel (jet fuel of kerosene type) [25]. The study was focused on measurements of temperatures and
energy feed-back from the flames to the fuel surface. Incident heat flux to the fuel surface measured by radiometers was in average 83 kW/m$^2$ in the JP-5 tests and 60 kW/m$^2$ in the methanol tests.

Radiative heat fluxes were measured also in a Swedish study [23]. Here the fluxes at different distances away from the fire were measured. In the tests with the largest pool size (50 m$^2$), the radiative heat flux at a distance of 2.0 m was ~10 kW/m$^2$ for methanol, which was low compared to the ~20 kW/m$^2$ measured from M15 fuel. In tests with a 4.0 m$^2$ pool, the radiative flux at 2.0 m distance was 2.6 kW/m$^2$ for methanol and 18.1 kW/m$^2$ for M15.

Spray fire characteristics of hydraulic fluids and some selected fuels including methanol were studied by Khan and Tewarson [26]. It was shown in their study that mineral oil and some organic esters had the highest combustion intensity followed by heptane, and that methanol had the lowest combustion intensity of the pure fuels tested. The fraction of radiative heat flux was further determined, where mineral oil showed the highest fraction (0.36) and methanol the lowest (0.14).

Experimental work on flash fires from turbulent, two-phase jet releases of propane was reviewed in [27]. They report from a study by Butler and Royle [28] that the concentration of gas in vapour clouds formed during experiments was generally low and the vapour cloud fires produced were relatively lean and the flames were therefore often invisible. Ignition of the cloud was observed at concentrations below the Lower Flammability Limit (LFL). This was explained to be due to localised pockets of high concentration of gas at locations when the average concentration was measured as being below the LFL. In some cases, the cloud was ignited, but the flame did not propagate throughout the cloud, resulting in the formation of isolated pockets of ignition. In the literature survey carried out, no information has been found specifically on experimental work on flash fires with methanol. However, CBS US Chemical safety board informs in a bulletin [29] that methanol can ignite at room temperature and has the potential for dangerous flash fires, especially when large quantities are present. The threat is quite similar to gasoline. This bulletin was issued on the background of a series of severe accidents in educational demonstrations.

In summary it is clear that the burning rate of methanol pool fires is significantly lower compared to conventional ship fuels. However, the mass burning rate (per area unit) increases with the pool area and small scale pool fire experiments should therefore be dismissed. Furthermore, the radiative heat flux from a methanol pool fire is significantly lower than from e.g. petrol. The impact from a spray fire of methanol is of less severity as both the combustion intensity and the radiative heat is low compared to conventional ship fuels. The potential for a flash fire is of concern but no quantification of the effects has been possible to make here.

### 2.4.2 LNG

Methane (CH$_4$) is the major component of LNG and is a gas at normal ambient temperature. Methane has the highest heat of combustion of the hydrocarbon fuels and burns efficiently with a limited soot production.

An accidental release of LNG from a limited leakage would evaporate immediately. The potential fire risks include ignition and explosion of the combustible methane/air mixture and also the onset of a spray fire with methane released from the leak source. A more substantial spill of LNG would result in a rapidly evaporating pool with an associated vapour cloud that is dispersed with the surrounding air. A pool fire scenario would only
be possible from a major release of liquid methane, where the methane/air mixture in the periphery of the evaporating liquid pool could burn.

LNG pool fires have been studied quite extensively, and pool fire experiments in various scales (~2 – 30 m pool diameters) have been reviewed by Woodward and Pitblado [30]. Even very large pool fire experiments (120 m diameter) were conducted in 2010 by Sandia Labs [31, 32]. From these series of experiments it has been shown that small pool fires burn brightly with almost no visible smoke, while large pool fires (e.g. >35 m diameter) become under-ventilated and produce visible smoke. It has also been shown [33] that the fire from a large pool radiates approximately as a black body, i.e. soot radiation is significant in addition to the radiation from water and carbon dioxide.

The burning rate (liquid regression rate) for a LNG pool fire has been reported to be different depending on whether the pool fire is on land (0.2 mm/s = 12 mm/min) or on water (0.6 mm/s = 36 mm/min) [30]. The regression rate of 0.2 mm/s corresponds approximately to a burning mass rate of 0.09 kg/m²s. The value for a land based pool fire was confirmed by small-sized Sandia tests where the regression rate was on average 0.3 mm/s. The regression rate was somewhat increased (0.35 mm/s) in larger pool fires conducted by Sandia [31].

The heat flux from a LNG pool fire is substantial and McGrattan et al. present a simplified method to make a prediction of the thermal radiation flux [21]. Input data needed include the mass burning rate of the liquid/gas. The total HRR of the fire was estimated by multiplying the mass burning rate by the heat of combustion. A mass burning rate of 0.08 kg/m²s is proposed which results in a total HRR per area unit of 4000 kW/m². This can be compared with the heat release per unit area for methanol of only 340 kW/m². Measured average radiative heat fluxes from some LNG pool fires (15 – 24 m in diameter) have been reported by Ufuah and Bailey [34] and were between 44 and 54 kW/m². This was significantly lower compared to the average flux of 70 kW/m² from two small (3-4 m diameter) diesel pool fires. However, modelling of the radiative heat flux from large LNG pool fires have shown higher fluxes relative to petrol and fuel oil [30]. Johnson and Cornwell [35] modelled the release of 12,500 m³ of LNG, LPG, and octane through a 1 m diameter hole onto sea water. The modelled maximum pool radius was the largest for octane (~150 m), smaller for LPG and the smallest for LNG (~70 m).

The combination of a larger pool, lower flame height and lower radiant flux for octane produces a similar radiant flux impact as LNG and LPG fires with smaller pools, taller flame heights and higher surface emissive power (SEP) values. The distance to a radiant flux of 30 kW was predicted to 375 m for octane, 280 m for LPG and 300 m for LNG. A similar comparison for a much smaller (500 m³) spill of LNG and light fuel oil [36] showed that since this fuel oil burns at a much lower rate, the flame height is considerably lower. The SEP of fuel oil is also lower (a smoky flame). This resulted in that the LNG fire radiative flux was considerably higher than that of fuel oil in this scenario.

A jet fire with LNG occurs when the liquid is released under pressure through a leakage point and is ignited. Woodward and Pitblado [30] review modelling of LNG jet fires and conclude that accurate models are available. Data is presented from modelling of ignited jets of vapour and liquid LNG (at 35 psig). As an example, the length of the fire jet was 9.5 m from a 2.54 cm diameter hole (discharge rate 0.4 kg/s) for vapour LNG, compared with 30.6 m for liquid LNG (discharge rate 4.5 kg/s). For methane or natural gas jet fires, the peak flame temperature inside the fire can be as high as 1252 °C [37] with an equivalent blackbody emissive power of 307 kW/m².

A flash fire is a risk at a release of methane from a leakage of LNG. A typical dispersing LNG cloud will be pancake shaped, its flammable phase will be a dense gas and ignition will normally be at the edge according to [30]. When the cloud is ignited, a combustion
wave moves through the cloud. Combustion velocities measured in the laboratory under laminar flow conditions [37] show that, in general, laminar burning velocities for paraffinic hydrocarbons range from a few centimetres per second near the flammability limits to about 45 cm/s near the intermediate stoichiometric concentration. Methane has a reported maximum laminar flame velocity under laboratory conditions of 36 cm/s, i.e. methane has a lower flame propagation velocity compared to other hydrocarbons. This means that unless ignition occurs during the initial rapid vaporisation period, it is most unlikely that a flash will accompany ignition. The term ‘lazy flame’ has been used to describe the spreading characteristics of an LNG fire. Regarding the radiation from flash-fires of LNG, [30] concludes that hardly any information is available from experiments on this issue.

To summarize the information above, pool fires of liquid LNG have a fast burning rate, which is 3 times as fast for a pool on water compared to a pool on land. The burning rate of a liquid LNG pool fire is much higher than that for methanol, and higher than for fuel oil. Calculations of the consequences of very large spills resulting in pool fires showed equivalent radiative fluxes from LNG and octane (model substance for petrol). However, the modelling of a considerably smaller spill volume (500 m$^3$) showed significantly higher heat flux from LNG compared to a spill of a light fuel oil. The release of LNG from a leak point resulting in a combustible fuel/air mixture will give a jet fire from the leakage point if ignited locally. In the case of ignition of a dispersing cloud of LNG a flash fire can occur if an ignition source is present. The combustion velocity for methane is, however, slow and late ignition of a cloud is unlikely to result in a flash fire.
3 Regulatory framework

Considering the particular properties of LNG and methanol discussed above, the suitability of IMO regulations and class rules was investigated at a workshop held 1 June 2015 at SP Fire Research. The focus at the workshop was specifically the possibilities for fire detection and fire extinguishment. Improved ways to manage these issues are further elaborated in the next section. The workshop included representatives from Flag, Class, ship designers, ship owners, system suppliers and experts in fire and explosion, as presented in Table 5.

Table 5 Attendance at workshop on active fire protection of LNG and Methanol installations.

<table>
<thead>
<tr>
<th>Company</th>
<th>Organization</th>
<th>Representative</th>
<th>Expertise</th>
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<tr>
<td>Swedish Transport Agency</td>
<td>Flag State</td>
<td>Saeed Mohebbi</td>
<td>Machinery and new fuels</td>
</tr>
<tr>
<td>Lloyd’s Register</td>
<td>Classification society</td>
<td>Kim Tanneberger</td>
<td>Low-flashpoint fuels</td>
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<tr>
<td>Lloyd’s Register</td>
<td>Classification society</td>
<td>Fabio Fantozzi</td>
<td>Fire safety</td>
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<tr>
<td>Stena</td>
<td>Ship owner</td>
<td>Mats Nilsson</td>
<td>Methanol safety</td>
</tr>
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<td>Marinvest</td>
<td>Ship owner</td>
<td>Kristoffer Tyvik</td>
<td>Methanol ship design</td>
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<td>Ship designer</td>
<td>Joakim Bomanson</td>
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<td>Tyco</td>
<td>System supplier</td>
<td>Henrik Johansson</td>
<td>Gas/water extinguishment</td>
</tr>
<tr>
<td>Consilium</td>
<td>System supplier</td>
<td>Martin Hagberg</td>
<td>Gas/fire detection</td>
</tr>
<tr>
<td>Ultrafog</td>
<td>System supplier</td>
<td>Martin Krogh</td>
<td>Water-mist suppression</td>
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<tr>
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<td>Research institute</td>
<td>Per Blomqvist</td>
<td>Fire emissions</td>
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<td>SP Fire Research</td>
<td>Research institute</td>
<td>Franz Evergren</td>
<td>Fire risk assessment</td>
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<td>Explosion protection</td>
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</tbody>
</table>

As basis for the workshop the following documents were used: the draft IGF Code applicable to LNG, submitted to the MSC for approval (CCC 1/13/Add.1), the CCC correspondence group draft guidelines applicable to methanol (CCC 2/3) and class rules for LNG and methanol fuelled ships. Fire safety in general is not regulated by Class but they often represent Flag States in fire related issues and their rules can therefore affect approval. Furthermore, additional fire related requirements affecting structures may also be presented by Class. The studied regulations and rules are further introduced below, followed by a summary of the investigations and general discussion.

3.1 Background to IMO regulations

In December 2003, Norway submitted a proposal to MSC 78 that new provisions for gas fuelled ships should be developed in SOLAS (MSC 78/24/8). This started the development of global regulations for internal combustion engine installations using gas as fuel. The item was in the work programmes of several sub-committees before draft interim guidelines on safety for natural gas-fuelled engine installations in ships were adopted at MSC 86 in 2009, MSC.285(86). Work had then also been initiated to develop this to an International Code of Safety for Gas-fuelled Ships under SOLAS, the IGF Code. However, in 2010 it was proposed by Sweden that the scope of the item should be extended to include alternative liquid fuels with low flashpoint (BLG 14/6/2). The extension of the item was agreed at MSC 87 and the title of the code being developed became “Code of safety for ships using gases or other low-flash point fuels”. At BLG 17

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1 This document was superseded at the time of issuing this report.
in 2013 it was nevertheless decided to prioritize finalizing the part of the IGF Code applicable to LNG, which had been most investigated and already taken into use on some ships at this point (BLG 17/18). It was also proposed by CESA (BLG 17/8/6) to consider several further fuels after the part on LNG had been finalized. The IGF Code, including the part applicable to LNG (A-1), was submitted to MSC and adopted at MSC 95 in 2015. The parts applicable to other fuels are under further development in the sub-committee CCC, where it was also decided that regulations for methanol should be developed as guidelines as a first step, followed by specific requirements to be incorporated in part A-2 of the IGF Code as a second step (CCC 1/13). The primary regulation development for methanol is carried out in a correspondence group coordinated by Sweden. The current draft of these regulations, submitted as CCC 2/3, worked as basis for the workshop discussions together with the adopted IGF Code, applicable to LNG. Until regulations for a particular low-flashpoint (<60°C) fuel have been ratified in a code, associated installations should be treated as alternative design and arrangements for fire safety and approved based on SOLAS II-2/17.

3.2 Regulations and rules for LNG

Subsequently the outcomes of investigations of the IGF Code and Class rules for LNG ship installations are presented. Initially the first chapters of the IGF Code were studied. It should be noted that adoption of the IGF Code regarding LNG will likely lead to reviews of the Class rules to reflect the former.

3.2.1 Preamble and general requirements of the IGF Code

Before the IGF Code specifies on different fuels in parts A-1, A-2 etc., a preamble and general requirements (Part A) are given. The preamble states that the IGF Code is supposed to address all areas that need special consideration for the usage of low-flashpoint fuels, which is quite a big task. However, the general requirements of the code require that a risk assessment is conducted to ensure that risks arising from the use of the fuel are addressed.

The basic philosophy of the code is a goal-based approach, which means that goals and functional requirements have been specified for each section, forming the basis for the design, construction and operation. For low-flashpoint fuels which lack prescriptive requirements, compliance with the functional requirements of the code should be demonstrated through alternative design. A leading functional requirement is that stating “The safety, reliability and dependability of the systems shall be [at least] equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery.” The following functional requirements seem to be sub-requirements to achieve this first functional requirement (3.2.1), which is very similar to that in SOLAS II-2/17 (3.4.2).

3.2.2 IGF Code Part A-1 for LNG

Fire safety regulations for LNG are found in chapter 11 of Part A-1 in the IGF Code. The goal of the chapter is “…to provide for fire protection, detection and fighting for all system components related to the storage, conditioning, transfer and use of natural gas as ship fuel.”

The chapter is initiated by requirements concerning passive fire protection in 11.3. Noteworthy is that it is stated that spaces with equipment for fuel preparation shall be regarded as a machinery space of category A. It is stated that this applies for fire protection purposes. It is interpreted that this does not only apply to this section, i.e. passive fire protection, but also to active systems.
In the following section, requirements are given for the fire main, followed by regulations for water spray systems in section 11.5. A water spray system shall be installed to cover exposed parts of a fuel tank on open deck as well as boundaries within 10 meters from such a tank. Cooling surrounding structures in such a way mitigates the consequences of a fire by preventing tank explosion and fire spread to surrounding structures.

Section 11.6 provides requirements for dry powder fire-extinguishing systems. A fixed system shall be installed to cover possible leak points in the bunkering station area. The definition of such points is not given.

In the next section, 11.7, are given requirements for fire detection and alarm. It is stated that such systems shall be installed in all spaces affecting the fuel system where fire cannot be excluded. This is not further defined. It is also stated that smoke detectors alone shall not be considered sufficient for rapid fire detection. However, no system proposal is given to specify what is supposed to be considered as sufficient. Such a vague formulation gives rise to many discussions.

Except from fire safety regulations, the related chapter 15 is relevant since it concerns control, monitoring and safety systems. The goal of the chapter is “…to provide for the arrangement of control, monitoring and safety systems that support efficient and safe operation of the gas-fuelled installation as covered in the other chapters of the code.” In particular, section 15.8 provides requirements for gas detection systems. It specifies that detectors shall be located where gas may accumulate and in the ventilation outlets. A gas dispersal analysis (CFD) or a physical smoke test shall be used to find the best arrangement. The detection system should give alarm at 20 % of LEL and stop the gas supply at 40% of LEL. These levels can be increased to 30 % and 60 %, respectively, in ventilated ducts around pipes (double mantling). Fire detection is managed in section 15.9, where it is simply stated that fire detection should activate an alarm.

### 3.2.3 Class rules for LNG

Since the IMO regulations were only awaiting final adoption at the time of the workshop, the class rules were quite tuned in with the IGF Code with regards to fire detection and fire extinguishment. Some differences were although noted, as specified below. The class rules studied were the Rules and Regulations for the Classification of Natural Gas Fuelled Ships, July 2012, incorporating Notice No. 1, 2 & 3 by Lloyd’s Register (LR) as well as the DNV-GL rules for Gas Fuelled Ship Installations.

Starting with LR’s rules, they state that spaces with equipment for fuel preparation and storage shall be regarded as a machinery space of category A. However, here it is specifically stated that this only applies for the purpose of determining fire integrity of boundaries, i.e. passive fire protection. This alleviates the requirements for fixed fire extinguishing-installations. Furthermore, certain boundaries are required to be A-60 divisions, for example boundaries facing gas storage tanks on open deck. For the water spray, dry powder fire-extinguishing and detection and alarm systems, requirements are very similar to the IGF Code. With regards to gas detection, the levels 30 % and 60 % of LEL apply instead of 20 % and 40 %, although with the same result. Furthermore, fire detection and alarm system are in LR’s rules required to be fitted in all spaces containing potential sources of gas leakage and ignition, not only in machinery and storage spaces. In addition, the fire detection system shall be so arranged that the activation of any fire detectors in hazardous areas, spaces containing gas-fuelled equipment, spaces adjacent to hazardous areas or gas-fuelled equipment, automatically shuts down the gas supply system.
The DNV-GL’s rules are almost equivalent to the regulations in the IGF Code with regards to fire safety. However, the DNV-GL rules clearly state that a compressor room or gas pump room shall be regarded as a machinery space of category A for fire protection purposes in general. This is a slightly different expression than that in the IGF Code and differs from that in LR’s rules. With regards to passive fire protection, additional requirements of A-60 divisions facing gas fuel tanks on open deck are found similar to in the LR’s rules. For the water spray, dry powder fire-extinguishing and detection and alarm systems, requirements are very similar to the IGF Code. An exception is that the requirements were not found for the water-spraying system to cover boundaries within 10 m from a tank on open deck, but this is likely due to an un-updated version studied. However, nothing is mentioned in the rules on how a complement to smoke detectors is necessary, as in the IGF Code.

3.3 Regulations and rules for methanol

Subsequently, the outcomes of investigations of the draft IMO guidelines and provisional Class rules for methanol ship installations are presented. It should be underlined that the IMO guidelines and class rules are under development at this stage and do hence not necessarily represent a suitable or well defined level of safety. The documents reviewed are under discussion and subject to changes.

3.3.1 Draft guidelines for methanol

The fire safety requirements are found in chapter 11 of the draft IMO guidelines for methanol installations. The goal of the chapter is “…to provide fire protection, detection and fighting for all systems related to storing, handling, transfer and use of methyl or ethyl alcohol as fuel.” Prescriptive requirements are given from section 11.4, where mainly requirements for passive fire protection are given. It is also stated that spaces with certain equipment are regarded as machinery space of category A. The certain equipment is specified as “fuel pumps, heat exchangers, pressure vessels etc.”. The “etc.” leaves room for interpretation, which is not desired in this kind of regulation.

In the section 11.5 are given requirements for the fire main and thereafter follow requirements for fixed fire-extinguishing and fire detection systems in section 11.6 (but the section is entitled fire-fighting).

A number of fixed systems are required:

- Foam fire-extinguishing system covering fuel tank on open deck and bunker station;
- Water-spraying system covering exposed parts of tank on open deck;
- Fire-extinguishing system in fuel pump room (fixed pressure water system in combination with foam);
- Fire detection and alarm system in all compartments containing fuel systems.

With regards to the foam fire-extinguishing and water-spraying systems for a tank on open deck it can be questioned how they are intended to be activated. Routines must be developed to ensure that the systems are not active simultaneously, which would diminish the effects of using foam. The definition of the fixed fire-extinguishing system for the fuel pump room does not follow the common nomenclature in SOLAS but it is assumed that what is intended is a system suitable for machinery spaces of category A, as specified in SOLAS II-2/10.4.1. However, this would not have had to be specified since it follows from the requirement in 11.4, that a space with fuel pumps should be regarded as a machinery space of category A, where such a fixed fire-extinguishing system is required. Furthermore it is simply stated “fixed pressure water system”, which likely refers to one
of the systems proposed in SOLAS II-2/10.4.1, namely a fixed pressure water-spraying fire-extinguishing system. This can be more clearly stated and also the way in which this should be combined with foam, which is only vaguely stated in the current draft. Another opening for interpretation is the statement to add detectors which are “suitable…based on the fire characteristics of the fuel” and which “can” detect methanol fire. A certain solution or options would be preferable in the prescriptive requirements.

Further requirements for fixed fire-extinguishing systems follow in section 11.7. It is once again stated that a fixed fire-extinguishing system suitable for a machinery space of category A is required in engine and pump rooms. As mentioned above, this follows already from SOLAS and has yet been stated in earlier requirements in the chapter. It is also required to install an approved foam fire-extinguishing system under floor plates in machinery spaces of category A. This may also be the intention of the requirement to combine a fire-extinguishing system with foam (in 11.6), which is in that case repeated here. It should although be noted that no such approved systems are available on the market. It is also difficult to design such a system since there are many pipes in the bilge which prevent the foam from covering the fuel surface.

### 3.3.2 Provisional Class rules for methanol

LR’s Provisional rules for the Classification of Methanol Fuelled Ships (Rule proposal No. 2014/E14) are in many ways similar to the draft IMO guidelines. Fire safety requirements are found in chapter 10, where it is initially stated that the arrangements are ultimately depending on a risk assessment of alternative design according to SOLAS II-2/17. Requirements for passive fire protection then follow in section 10.2, followed by specifications for the fire main. In sections 10.4 and 10.5 follow requirements for fire extinguishing systems on open deck. A water-spraying system achieving MSC.1/Circ.1430 should cover exposed parts of fuel tanks and boundaries facing the tanks. Furthermore, a fixed foam fire-extinguishing system should be installed with coverage depending on the (regulation 17) risk assessment. The references to the guidelines for design of fire-extinguishing systems on ro-ro decks MSC.1/Circ.1430 and to SOLAS II-2/17 are new, but in general the requirements are the same as in the draft IMO guidelines. In section 10.6 follows a requirement of a fixed fire-extinguishing system in machinery spaces were equipment containing fuel is located. The system is required to achieve MSC/Circ.1165, which are guidelines for water-based fire-extinguishing systems in machinery spaces and cargo pump-rooms. These are used to approve water-mist systems, which hence imply a difference in comparison with the draft IMO guidelines which require a water-spraying system. Furthermore, no foam fire-extinguishing system is required under floor plates in the LR’s rules and nothing is mentioned on the particularities of fire detection.

The DNV-GL Tentative Rules for Low Flashpoint Liquid Fuelled Ship Installations (Part 5, chapter 32, July 2013) are also to a large degree similar to the draft IMO guidelines for methanol installations. Fire safety requirements are found in section 4, where passive fire protection requirements are initially given in sub-section B. Requirements for fire-extinguishing systems are given in the following sub-section C, where it is stated that a fixed foam fire-extinguishing system should cover a fuel tank on open deck as well as the bunker station. The requirements are similar to those in the draft IMO guidelines but somewhat more detailed. There is although no clear requirement for a separate water-spraying system covering fuel tanks on open deck, as in other regulations. The requirements for an approved fire-extinguishing system in the pump room are similar to those in the draft IMO guidelines but yet different. It is stated that an approved fire-extinguishing system is required and also that a fixed pressure water-spraying system and high expansion foam may be considered. This formulation is rather vague. It is not emphasized that the two referenced systems should be used in combination as in the draft
IMO guidelines or whether it is a bilge foam fire-extinguishing system that is intended (high expansion foam is for example commonly used for total flooding). It is interpreted that water-spraying and foam fire extinguishing systems are given as examples of systems to consider for total flooding but that the requirement is that the system is approved, which is although also unspecified. An approved fixed fire-extinguishing system suitable for machinery spaces of category A is required in main engine rooms with methanol engines, as in the draft IMO guidelines. However, in the DNV-GL rules is given a guidance note with a recommendation to use an approved water-mist system in combination with an approved bilge foam fire-extinguishing system. The water-mist recommendation is hence similar to the requirement in the LR’s rules, but here together with a fire-extinguishing system under the floor plates, as in the draft IMO guidelines. As stated above, a problem is that no such bilge fire-extinguishing systems are yet approved. Furthermore, the available fixed water-mist fire-extinguishing systems are only approved for relatively small engine room volumes (in particular ceiling heights), which can make it difficult to achieve such regulations. It is also noted in the DNV-GL rules that none of the extinguishing systems approved by the FSS Code have been tested for LFL fuels and that such installations will need additional acceptance by Flag authorities. This is not perfectly formulated but the intention of the note is vital. Systems which are tested in accordance with the FSS Code and referenced circulars to be approved for machinery spaces of category A are in fact tested with low-flashpoint fuel. Heptane is one of the fuels included in the tests and has a flashpoint below 0°C. Furthermore, since fire safety is a Flag issue it is always up to the Flag authority to decide on the acceptance of fire-extinguishing systems. Nevertheless, the extinguishing systems approved under SOLAS are not designed to account for the many particularities of methanol, combined with a low flashpoint.

### 3.4 Summary of regulation investigations

A summary of the IGF Code and Class rules from LR and DNV-GL for LNG installations is provided in Table 6 with regards to fire extinguishing systems. It indicates quite good resemblance between the regulations and rules. The only difference is that the DNV-GL rules do not specify that boundaries within 10 m from a tank on open deck should be covered by a pressure water-spraying fire-extinguishing system.

**Table 6** Different requirements for fire-extinguishing systems for LNG installations (green indicates converging requirements).

<table>
<thead>
<tr>
<th>LNG</th>
<th>IGF Code</th>
<th>LR</th>
<th>DNV-GL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tank on open deck</strong></td>
<td>Water spray</td>
<td>Water spray</td>
<td>Water spray</td>
</tr>
<tr>
<td><strong>Boundaries within 10 m from tank</strong></td>
<td>Water spray</td>
<td>Water spray</td>
<td>-</td>
</tr>
<tr>
<td><strong>Bunker station</strong></td>
<td>Water spray and Powder</td>
<td>Water spray and Powder</td>
<td>Water spray and Powder</td>
</tr>
<tr>
<td><strong>Engine room</strong></td>
<td>System approved for mach. cat. A</td>
<td>System approved for mach. cat. A</td>
<td>System approved for mach. cat. A</td>
</tr>
</tbody>
</table>

Except from the difference noted in Table 6, the prescriptive requirements appear the same. However, another important implicit difference was found which affects requirements for fire-extinguishing systems, namely the type of spaces that should be considered as machinery spaces of category A.
The studied requirements give dissimilar definitions to the spaces that should fall in this category, as summarized below:

- **IGF Code**: Spaces with equipment for fuel preparation;
- **LR**: Spaces with equipment for fuel preparation and storage (applying only for fire integrity requirements);
- **DNV-GL**: Compressor or gas pump rooms.

The LR’s definition is somewhat wider than that found in the IGF Code but it only applies for the specification of passive fire protection. The definition in the DNV-GL rules applies for active fire protection systems but is narrower than that in the IGF Code by specifying certain fuel preparation equipment. Since no further requirements are found for fixed fire-extinguishing systems in spaces, this definition can make a big difference.

Considering fire detection there were also differences found between the rules and regulations. The IGF Code specifies that it is insufficient to use only smoke detectors in spaces affecting the fuel system. This is not mentioned in the Class rules and no solution is proposed in the IGF Code. The action upon fire detection also varies somewhat between the regulations and rules and also the levels which should generate alarm and stop of fuel transfer upon gas detection.

Reflecting upon the requirements for LNG installations it is noted that active systems for fire protection are only added on open deck. The focus seems to be to mitigate the consequences of a fire by protecting potentially exposed boundaries, the tank and the bunker station, which could all generate a larger fire. It should be noted that it is very unlikely that these measures will extinguish an LNG fire on open deck. Hence, the measures exist to reduce the potential for fire spread. It should also be noted that bunker station should be protected with both water-spraying and dry chemical powder fire-extinguishing systems but that effects from the latter will be diminished if the systems are activated simultaneously. For interior spaces there are no requirements for extinguishing an LNG fire, for example in the engine or pump rooms. The general principle appears to be to prevent leakage, both in interior spaces and on open deck. This could be much more clearly stated in the IGF Code and Class rules. Fire safety regulations are generally structured to address all stages of fire development, from prevention of ignition and fire growth to suppression and structural fire resistance. It can be questioned if the IGF Code, relying heavily on avoiding a fire in LNG, provides robust management of fire safety. In parallel it must although be considered that many conventional means for fire-extinguishing cannot be used for LNG, as further discussed in the following section.

A summary of the draft regulations and rules for methanol installations is presented in Table 7. It shows significantly more differences in the requirements than in those applying to LNG installations. Foam is uniformly required for at bunker stations and for tanks on open deck. For the latter, the draft IMO guidelines also require coverage by a water-spraying system. This is also required by the LR’s rules, but with reference to the guidelines developed for ro-ro deck spaces. The DNV-GL rules do not include any requirement to cover tanks on open deck by water-spray.

In the pump room the DNV-GL requires an “approved fire-extinguishing system”, without further specification, whilst the draft IMO guidelines require pressure water in combination with foam, without further specification. The implication is likely a fixed pressure water-spraying fire-extinguishing system but how it should be combined with foam is not determinable (foam as additive, bilge foam fire-extinguishing system, complimentary foam total flooding system?). The LR’s rules implicitly require a water-mist system by requiring an approved system and referring to MSC.1/Circ.1165. The same applies to engine rooms. Here DNV-GL requires an approved system for machinery.
spaces of category A and recommends using water-mist in combination with an approved bilge foam fire-extinguishing system. Such a system under the floor plates is required in engine rooms also by the IGF Code, in combination with an approved system for machinery spaces of category A (i.e. not necessarily water-mist). It should although be noted that no approved bilge fire-extinguishing systems exist.

Table 7 Different requirements for fire-extinguishing systems for methanol installations (green indicates converging requirements).

<table>
<thead>
<tr>
<th>Methanol</th>
<th>Draft IMO guidelines</th>
<th>LR</th>
<th>DNV-GL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank on open deck</td>
<td>Foam and</td>
<td>Foam* and</td>
<td>Foam</td>
</tr>
<tr>
<td></td>
<td>Water spray</td>
<td>Water-spray**</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(MSC.1/Circ.1430)</td>
<td></td>
</tr>
<tr>
<td>Bunker station</td>
<td>Foam</td>
<td>Foam*</td>
<td>Foam</td>
</tr>
<tr>
<td>Pump room</td>
<td>Pressure water (spray?) and Foam</td>
<td>Approved water-mist (MSC.1/Circ.1165)</td>
<td>&quot;Approved&quot; system</td>
</tr>
<tr>
<td>Engine room</td>
<td>System approved for mach. cat. A and &quot;Approved” bilge foam system</td>
<td>Approved water-mist (MSC.1/Circ.1165)</td>
<td>System approved for mach. cat. A (recommendation of water-mist in combination with “approved” bilge foam)</td>
</tr>
</tbody>
</table>

* Coverage depending on risk assessment
** Coverage extending to boundaries facing tanks

With regards to fire detection, issues related to detection of a methanol fire are only considered in the draft IMO guidelines. They require adding suitable detectors in all spaces with fuel systems, but no further specification for how this should be achieved is given.

A general reflection on the regulations and rules for methanol installations is that requirements to a larger degree are formulated in a traditional way. Even though similar means as for LNG are taken to avoid making methanol available and to prevent ignition and fire, it is still required offensively manage a methanol fire. This is not the case for LNG, where avoiding fire and further fire spread seem to be the only protective measures against fire. The requirements on how a methanol fire should be offensively fought vary; likely due to lack of knowledge in how this is best accomplished. This is for example verified in a guidance note in the DNV-GL rules which concludes that approved fire-extinguishing systems have not been tested for methanol. For this reason it is somewhat remarkable that requirements are still given for the fire-extinguishing and detection systems to be used.
4 Gas and fire detection

The regulations discussed above require fixed gas and fire detection systems for low-flashpoint fuel installations in a number of locations, as discussed above. The effectiveness of these and other potential systems for the relevant fuels is discussed below. Proposals are also made for how sufficient performance of the systems can be ensured by tests.

4.1 Requirements for detection systems

Detection and alarm is in SOLAS covered in chapter II-2, regulation 7. The Regulation includes requirements for fixed fire detection and fire alarm systems, manually operated call points and fire patrols. In all machinery spaces a fixed fire detection and fire alarm system shall be installed and the prescriptive requirements state that the detection system shall “…detect rapidly the onset of fire in any part of those spaces and under any normal conditions of operation of the machinery and variations of ventilation as required by the possible range of ambient temperatures.” Detection systems with only heat detectors are not permitted, unless especially appropriate. The function of the detection system under variations of ventilation shall be tested after installation. Furthermore, the function of the system shall be periodically tested with appropriate hot air, aerosol particles or other phenomena to which the detector is designed to respond.

For detailed requirements on system performance it is in regulation 7 referred to the Fire Safety System (FSS) Code. It specifies requirements from SOLAS chapter II-2 and refers to standards and guidelines to define many of the requirements. Fire detection and alarm systems shall comply with chapters 9 and 10 of the FSS Code. Chapter 9 manages point heat detectors and smoke detectors of point type and chapter 10 manages sample extraction smoke detection systems (aspirated smoke detection systems). The most relevant requirements are summarized in the following sections.

4.1.1 Requirements for point fire detection and alarm systems

In the general requirements in chapter 9 of the FSS code it is stated that any fixed fire detection and fire alarms system with manually operated call points shall be capable of immediate operation at all times. The fixed fire detection and fire alarm system shall not be used for any other purpose, except that closing of fire doors and similar function may be permitted at the control panel. The system and equipment shall be suitably designed to withstand difficult operational conditions like supply voltage variation and transient, ambient temperature changes, vibration, humidity, shock, impact and corrosion normally encountered in ships. Furthermore, at least two power sources shall exist to power electrical equipment used for fixed fire detection and fire alarm system. One of these should be an emergency power source.

Considering detectors it is required that they shall be activated by heat, smoke or other products of combustion, flame, or any combination of these factors. Detectors that will be activated by factors of incipient fires may be considered by the Administration, provided that they are no less sensitive than detectors activated by products. Flame detectors shall only be used in addition to smoke or heat detectors. All detectors should however be of a type such that they can be tested for correct operation and restored to normal surveillance without the renewal of any component.

Smoke detectors are required in stairways, corridors and escape routes within accommodation spaces and shall be certified to operate between 2-12.5 % obscuration per meter (≈0.09-0.58 dB/m). Smoke detectors installed in other spaces shall activate within
sensitivity limits to the satisfaction of the Administration having regard to the avoidance of detector insensitivity or oversensitivity.

Heat detectors shall be certified to activate between 54-78°C for a temperature raise less than 1 °C/minute. In a higher temperature raise the detector shall operate within temperature limits that will satisfy the Administration regarding avoidance of insensitivity or oversensitivity. In drying rooms and similar spaces, where the normal ambient temperature is high, the activation temperature may be up to 130°C, and up to 140°C in saunas.

With regards to positioning of the detectors it is required that they shall be located for optimum performance. Position close to beams and ventilation ducts where patterns of airflow could adversely affect the performance should be avoided. Positions where impact or physical damage is likely should also be avoided. The maximum spacing of detectors is shown in Table 8.

Table 8  Spacing of detectors.

<table>
<thead>
<tr>
<th>Type of detector</th>
<th>Maximum floor area per detector [m²]</th>
<th>Maximum distance apart between centres [m]</th>
<th>Maximum distance away from bulkheads [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>37</td>
<td>9</td>
<td>4.5</td>
</tr>
<tr>
<td>Smoke</td>
<td>74</td>
<td>11</td>
<td>5.5</td>
</tr>
</tbody>
</table>

The Administration may require or permit different spacing than specified in Table 8 if based on test data which show the characteristics of the detectors.

Electrical wiring which forms part of the system shall be so arranged as to avoid galleys, machinery spaces and other spaces of high risk. This is to avoid damage on the electrical wiring. Exceptions could however be accepted for spaces where it is necessary with fire detection or connecting to appropriate power supply.

The activation of any detector or any manually operated call point shall start an audible and visual fire signal at the control panel and indicate the activated unit. If the signals not have received attention within two minutes, an audible alarm shall be automatically sounded in the crew accommodation, service spaces, control stations and machinery spaces. The control panel should also give an audible and visual false signal in case of power loss or failure in electric circuits for the detection system.

4.1.2 Requirements for sample extraction smoke detection

In the general requirements in chapter 10 of the FSS code it is stated that the system and equipment shall be suitably designed to withstand a number of disturbing conditions: supply voltage variation and transient, ambient temperature changes, vibration, humidity, shock, impact and corrosion normally encountered in ships. These conditions are common on ships and must be resisted to avoid the possibility of ignition of a flammable gas-air mixture. As in chapter 9 it is required to provide the system with alternative power supply. The system shall also be of a type such that they can be tested for correct operation and restored to normal surveillance without the renewal of any component.

In the component requirements it is stated that the system must be certified to activate before the smoke density within the sensing chamber exceeds 6.65 % obscuration per meter (≈0.3 dB/m). The system shall also be provided with an arrangement for periodically purging and clean the pipes with compressed air. The control panel shall permit observation of smoke in the individually sampling pipe. It shall be able to monitor the airflow through the sampling pipes.
The sample pipes shall be a minimum of 12 mm internal diameter except when it is used together with a fixed gas fire-extinguishing system. In those cases the minimum size shall be sufficient to permit the fire-extinguishing gas to be discharged within the appropriate time. The sampling pipe arrangements shall be such that the location of the fire easily can be identified.

4.1.3 Additional detection requirements in the IGF Code

In Part A-1 of the IGF Code, applying to ships using LNG as fuel, gas detection is regulated in chapter 15 and fire detection in chapter 11. As discussed in chapter 3 above, gas detectors shall be fitted where fuel vapours may accumulate and in the ventilation outlets. At 20 % of the lower explosion limit (LEL) the detector shall give an alarm (up to 30 % if the detector is located in ventilated ducts) and at 40 % of LEL at two detectors the fuel supply shall be stopped (60 % in ventilated ducts). The gas detection shall be continuous without delay. Regarding fire detection by other means than by gas detection, Part A-1 of the IGF Code refers to the FSS Code in the same way as SOLAS chapter II-2, regulation 7. The only additions are details over what premises shall be protected and that smoke detectors alone shall not be considered sufficient.

In the draft IMO guidelines applying to ships using methanol as fuel, the requirements for fire detection are similar to those in Part A-1.

4.2 Considerations for low-flashpoint fuels

Low-flashpoint fuels (LFFs) are in general more likely to cause accumulation of flammable vapours, in particular fuels with flashpoint below room temperature. This requires some sort of gas detection.

Detection of fire is normally based on measurements of physical phenomena that change or arise in case of fire, e.g. temperature increase, smoke production, electromagnetic radiation or gas production. Depending on the fuel composition, combustion efficiency and size of the fire, certain phenomena (signatures) will be prominent. Most detection systems are generally designed to detect fire signatures such as smoke production, heat production and radiation. Most solid and petroleum based fuels are known to generously generate such signatures. However, the fire signatures of some LFFs are different. For example, some fuels will have almost invisible flames and very low smoke production, which also affect the possibilities for the fire patrols. Below are discussed special considerations for Liquefied Natural Gas (LNG) and methanol as fuels.

4.2.1 Detection of LNG

Below are discussed gas detection and fire detection specifically for LNG.

Gas detection

LNG has a boiling point below -160°C, which means that a potential leakage will rapidly turn into gas and spread out in the space. If not a very large leakage, the LNG will in a short time be vaporised to gas phase. This implies that it is more likely with an explosion than with a localized fire when dealing with LNG. Consequently, gas detection is an important mean for protection.

Detection of explosive gases is most often associated with detection of different hydrocarbons. For LNG the main constituent is methane (CH₄), which hence is the substance easiest to detect. There are different principles and technologies available for gas detection with different advantages and disadvantages. The conventional, simple and
low cost catalytic sensor is often used. However, it requires frequent calibrations, surrounding oxygen and relatively high power. Another alternative is based on infrared, IR, technology. It is more robust and can be used in inert atmospheres, but to a higher initial cost. With IR it is also possible to use “open path” detection, which means that a transmitter and a receiver are positioned apart from each other and that detection is achieved along the whole distance in-between. Other technologies include semiconductors, electrochemical sensors, thermal conductivity sensors and absorbent filter tape. One solution that often uses semiconductors is the “electronic nose” (multiple gas detection). This detector registers several different gases and by pattern recognition it can “sniff” e.g. a specific fuel leakage or a fire. Some technologies are more suitable for toxic gases and other for flammable/explosive gases. In general, toxic gas detection needs more sensitive detectors since the levels of toxic gases that may be harmful for human are often much lower than LEL (lower explosion limit) of flammable gases. However, LNG is classified as non-toxic. Nevertheless, the vapours are not harmless to inhale.

Most technologies used for gas detection are associated with point detection. However, instead of using several separated point detectors, an alternative is to use an aspirating system, which means that air/gas is sampled from several positions to one sensor. The advantage is that one sensor can cover a larger area, but if several sampling points are used there is a dilution problem and the sensor often needs to be much more sensitive than a corresponding sensor of a point detector.

Another way to detect a gas leakage is by the heat radiation. Everything with temperature above 0 K will radiate heat and this can be captured by a thermal imaging camera. A specific gas will radiate at specific wavelengths and by looking at the changes of radiation at these wavelengths a real-time video of the gas distribution is produced. The gas leakage can then be monitored, however, it is hard to determine exact gas concentrations.

An additional possibility to detect a gas leakage of LNG, without the possibility to measure gas concentration, is by linear heat detection. A sensitive linear heat detector can be installed along pipes to give an alarm in case of cold natural gas outside of the pipe, indicating a leakage.

In case of a leakage, natural gas will spread quickly in the space, but can be both heavier and lighter than air depending on the gas temperature. When cold it will be heavier, but when warmed up by the surrounding air the natural gas will be lighter. Positions of LNG gas detectors in the ceiling and in the ventilation system as well as low positions close to potential leakages should be considered. In case of a LNG gas detection alarm, required actions are, depending on alarm level, increased ventilation and/or cutting off fuel supply. Activation of a water-mist system could potentially push the gas away and also prevent ignition, but the effect of suppression systems on a gas alarm must be evaluated further.

**Fire detection**

As discussed above, there will most likely not be a localized fire only containing LNG as fuel. For this to occur there has to be such a large leakage that all LNG is not vaporised before ignition or that ignition happens when the leakage starts, resulting in e.g. a jet fire from a pipe. A large interior fire will soon also contain other fuels, resulting in a fire easily detected by conventional fire detection systems. However, if a jet fire occurs it could be relevant to use flame detectors. A flame detector would also detect a large pool fire faster than e.g. a smoke detection system. A more comprehensive discussion of different fire detection systems for “clean” burning fuels is provided in the section on methanol below.
A higher risk in case of a LNG leakage is that involving explosion. The gas detection system should ensure that the explosion limit is not reached. However, it may occur that ignition takes place before high levels of natural gas have been detected, resulting in a small explosion. For such a scenario it could be relevant to consider an explosion detection system to provide for faster reaction. An explosion can be detected by pressure differences, sound or electromagnetic radiation.

### 4.2.2 Detection of methanol

Below are discussed gas detection and fire detection specifically for methanol.

#### Gas detection

The flashpoint of methanol, 11°C, will most likely always be lower than the ambient temperature on a ship space with methanol installations. This means that a leakage will most likely evaporate in sufficient amount to be ignitable. A gas detection system is therefore needed to detect such a leakage. However, the vapour density of methanol is slightly higher than that of air (1.1 relative 1.0 for air, see Table 2). This means that it will take a longer time for the vapours to reach the ceiling compared to natural gas which has lower density (methane, the main constituent in natural gas, has a relative density of 0.55 at room temperature). This affects the positioning of gas detectors. Positions close to potential leakages as well as positions in the ceiling and in the ventilation system should for example be considered.

Detection of methanol vapour can be achieved by several different technologies, as discussed for LNG above. Appropriate action on methanol gas detection should be, as for LNG, increased ventilation, to cut off fuel supply and potentially activation of water-mist. A complement for increased safety and to limit the accumulation of flammable vapours may also be installation of a drainage system.

#### Fire Detection

In general, combustion of a substance produces carbon dioxide, water, soot and heat. This also applies to combustion of methanol. What distinguishes methanol from most solid and petroleum based fuels is the amount of soot produced. Burning methanol gives a very “clean” combustion, meaning that almost no soot is produced, as illustrated in Figure 4. Soot particles are a result of incomplete combustion and usually appear in the shape of spheres, crushed chunks or long chains [38]. These particles are what make smoke black and the flames luminously yellow. From a detection point of view, soot is an easily recognizable phenomenon for automatic (and human) detection.

![Figure 4](image)
A commonly used automatic fire detector is the optical smoke detector which is triggered by an increase of particles in the air. The smoke detector is generally claimed to give earlier detection than e.g. the heat detector, which is valid for many fuels producing much soot when burning, e.g. solids and petroleum based products. Smoke production is for these fuels namely high in comparison with the released heat at the early stages of a fire. However, methanol is a clean fuel and detection advantages of soot do not apply. Without soot, the flames and smoke (combustion gases) will be almost invisible. A smoke detector will therefore most likely not trigger until later into the fire. A way around this is to use additives which make the methanol fire less clean. However, there are generally requirements on the methanol fuel provided to be very clean, which prevents the use of additives. A fire in only methanol could then be detected from other fire signatures, such as heat, electromagnetic radiation, or gases.

One alternative is to use flame detectors detecting in the infrared region. They should be triggered by electromagnetic radiation emitted by carbon dioxide. Since almost no soot is produced in a methanol fire, the radiation from carbon dioxide is more significant than for most sooty flames. This is because soot particles can absorb radiation from carbon dioxide. Figure 5 shows the infrared spectrum of carbon dioxide. Where the transmittance is low the absorption is high, which means that the carbon dioxide molecule will radiate at these wavelengths. Most common is to detect carbon dioxide radiation from the narrow spectral band around 4.3 µm (2326 cm\(^{-1}\)). As can be seen in Figure 6 the transmittance through water is high at this wavelength, which is important such that the radiation from the carbon dioxide is not absorbed by water molecules in the air. This is the reason why detection around 3700 cm\(^{-1}\) (2.7 µm) is less suitable. Flame detectors approved by the European Standard EN 54-10 or the International Standard ISO 7240-10 are tested against both sooty and non-sooty flames. The non-sooty test fire in these standards is methylated spirit containing mostly ethanol and is classified to “represent a fire burning with a clear (invisible) flame”. This should ensure good detection of a methanol fire, however, this should be verified.

Figure 5  Infrared transmittance spectrum of carbon dioxide (CO\(_2\)) [39].
Another way of detecting a methanol fire is to detect the generated heat. However, less heat is generated in a methanol fire compared to e.g. a diesel fire as discussed in section 2.4.1. Nevertheless, detecting heat could be a good alternative if the ceiling is low and the space is small. Heat detection is considered a bit slower than other technologies, but there are also more advanced and more sensitive heat detection systems, such as systems based on fibre optics. When heated, the refractive index of the glass changes and the laser pulses sent into the fibre optic cable will backscatter. This enables detection of heat, as well as the exact position of the hot spot.

A third alternative to detect a non-sooty fire is by different produced gases. This could be combined with the gas detection system used to detect leakage (before fire). For example, oxygen and carbon dioxide can be monitored to detect when the air is contaminated, indicating a gas leakage. The same system may be used to give a fire alarm in case of an increase of carbon dioxide.

Sometimes CCTV cameras are used for fire detection. Image analysis software is then used to identify possible fires and give an alarm. The benefits of such systems are that surveillance and fire detection are combined, but also that the extent and position of the fire is easily monitored in case of an alarm. However, to be used for methanol fires the CCTV must register infrared radiation. Thermal imaging cameras are thus needed, which may be an expensive investment. There are also solutions on the market that combines CCTV in the visual spectrum with conventional flame detectors. With software-based communication the CCTV can monitor the fire in case of an alarm from the flame detector.

Fire patrols generally detect fire by seeing flames or smelling the generated smoke. As described earlier, a methanol fire generates significantly less smoke and visible flames than conventional fuels. It may therefore be hard to detect and localize by the human eye. To ensure that an outbreak of fire mainly involving methanol can be promptly detected and localized, fire patrols could be equipped with hand held thermal imaging cameras for use in firefighting. Figure 4 illustrates the benefit of a thermal imaging camera for a methanol fire.
5 Fixed fire extinguishment

The regulations discussed above require fixed fire-extinguishing systems for lowflashpoint fuel installations in a number of locations, as summarized in Table 6 and Table 7. The effectiveness of these systems for the relevant fuels is discussed below. Proposals are also made for how sufficient performance of the systems can be ensured by tests.

5.1 General requirements in SOLAS

As for general requirements, SOLAS chapter II-2, regulation 10 requires that a fixed fireextinguishing system shall be installed in machinery spaces on board ships and that fireextinguishing appliances shall be readily available. This requirement applies also to cargo pump-rooms in tankers in accordance with regulation 10.9.1. It should also be noted that according to regulation 1.6.1, requirements for tankers in the fire safety chapter apply to tankers carrying crude oil or petroleum products having a flashpoint not exceeding 60°C, e.g. methanol.

Machinery spaces of category A\(^\text{ii}\) containing internal combustion machinery shall be provided with a fixed fire-extinguishing system. Any of the three following types of systems may be used:

1. a fixed gas fire-extinguishing system;
2. a fixed high-expansion foam fire-extinguishing system; or
3. a fixed water-spraying system fire-extinguishing system.

The FSS Code also allows different equivalent fixed fire-extinguishing systems, such as water-mist systems approved according to MSC/Circ.1165 or fixed aerosol fireextinguishing systems approved according to MSC/Circ.1007. The systems listed above and systems considered equivalent in accordance with those standards are thus in SOLAS considered to be sufficient and effective in providing fire protection in compartments with installations handling methanol and LNG. Equivalent fixed fire-extinguishing systems, e.g. water-mist fire-extinguishing systems, are tested using high and lowflashpoint fuels by the inclusion of diesel and heptane (flashpoint -4°C) in the fire test procedures. However, there are other properties of both methanol and LNG which make the fuels special when considering fire extinguishment, as further discussed below.

For passenger ships of 500 gross tonnage and above, and cargo ships of 2000 gross tonnage and above, machinery spaces of category A, in excess of 500 m\(^3\), shall in addition to the ‘total flooding system’ listed above, be protected by an approved type of water-based or equivalent fixed local application fire-extinguishing system. Such systems shall comply with the installation guidelines, component tests and fire test procedures in MSC/Circ.913, as amended by MSC/Circ.1082 and MSC/Circ.1387. Typically, the systems that are approved are low-pressure or high-pressure water-mist systems. The activation of the fixed local application fire-extinguishing system should not require engine shutdown, closing of fuel tank outlet valves, evacuation of personnel or sealing of the space. Any of these actions would lead to loss of electrical power or reduction of manoeuvrability.

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\(^{ii}\) Machinery spaces of category A is defined as those spaces and trunks which contain either:
1. internal combustion machinery used for the propulsion;
2. internal combustion machinery used for purposes other than main propulsion where such machinery has in the aggregate a total power output of not less than 375 kW; or
3. any oil-fired boiler or oil fuel unit, or any oil-fired equipment other than boilers, such as inert gas generators, incinerators, etc.
Details on test requirements for fixed fire-extinguishing systems are given in Appendix A.

5.2 Gas fire extinguishment of methanol

When carbon dioxide is used the system should be designed in accordance with the fire safety systems (FSS) code. It requires that that the carbon dioxide system should be designed to give a minimum volume of free gas equal to at least 40% of the space (excluding the casing).

When other inert gases or halocarbon agents are used, the system performance should be verified in accordance with MSC/Circ.848 [41]. This circular states that alternative fixed gas fire-extinguishing systems should have an inert gas design concentration based on the minimum extinguishing concentration (MEC), as determined by a cup burner test (see e.g. Annex B in ISO 14520-1 [42]). The design concentration should be at least 20% above the MEC and the performance of the system should be verified by large-scale testing according to MSC/Circ.848 [41]. It requires the systems to extinguish different combinations of heptane pool fires, light diesel spray fires and wood crib fires.

The cup burner extinction for several agents show a larger amount of agent requirement for methanol as compared to n-heptane (including the chemical catalytic halon 1301–CF3Br, chemically scavenging 1,1,1,2,3,3,3-heptafluoropropane and physical agents such as N\textsubscript{2}, CF\textsubscript{4} and IG-combination gases) [43, 44]. The suppression differential between methanol and heptane is very large for halon 1301 (>2x) [45]. Methanol also requires greater agent concentrations for N\textsubscript{2}, CF\textsubscript{4} [45], IG-55 [46] and IG-541 [47] as compared to n-heptane (1.25-1.4x). These work primarily by physical mechanism, just as carbon dioxide.

The only found test result from a cup burner test with carbon dioxide to extinguish methanol is that in a paper by Takahashi et al. [48] who measured a MEC of about 27%. This value for methanol may be questioned since it is based on a single test reference.

The MEC of an inert gas working by physical mechanism may also be calculated from data for other physical agents with knowledge that the MEC is inversely proportional to the heat capacity of the gas [49]. Hence, if exact MEC data for one gas (carbon dioxide) is not known, it can be learned from another inert gas for which data exists. The ISO 14520 standard parts for different agents are helpful here. For example, table 5 in ISO 14520-15 [47] states that the MEC for IG-541 (a blend of 52% N\textsubscript{2}; 40% Ar; 8% CO\textsubscript{2}) to extinguish diesel is 35.8% and to extinguish methanol 44.2%. When assessing the performance of an inert gas as an extinguishing agent the parameter of interest is the mole fraction of the added inert gas at the point of extinguishment, which can be defined according to Equation 1 [49].

\begin{equation}
MEC_g = \frac{\vartheta_g}{\vartheta_{air} + \vartheta_g} \quad \text{Eq. 1}
\end{equation}

\begin{equation}
Q = \Delta H_p + \vartheta_g \Delta h_g \Rightarrow \vartheta_g = \frac{Q - \Delta H_p}{\Delta h_g} \quad \text{Eq. 2}
\end{equation}

where \( \vartheta_g \) is the quantity of added inert gas per mole of fuel and \( \vartheta_{air} \) is the quantity of air per mole of fuel. Energy balance gives Equation 2, where \( Q \) is the heat of combustion per mole of the fuel, \( \Delta H_p \) is the energy absorbed by the normal combustion products and \( \Delta h_g \) is the energy absorbed per mole of added inert gas. The numerator in Equation 2, solved for \( \vartheta_g \), is hence a constant depending on the fuel and the denominator is a constant...
depending on the inert gas. The former may be calculated from the MEC values for IG-541 and the latter are known as 45.7 kJ/mole for IG 541 and 82.1 kJ/mol for CO₂ [49]. Thereby the MEC for carbon dioxide to extinguish methanol was calculated to 30.6 %, which was 29 % higher than the MEC calculated for diesel and 38 % higher than that for n-heptane.

Another way to derive the MEC of carbon dioxide for methanol is based on the Swedish Fire Protection Association regulations for carbon dioxide fire-extinguishing systems, SBF115:2 [50]. These state that the design concentration should be increased by 22 % and 3 %, for methanol and n-heptane respectively, in comparison to a system designed for diesel (see Table 5.412 in SBF115:2). If consistent safety margins have been applied to the different fuels in the table in SBF 115:2, the numbers should correspond their MEC data. Thus, the MEC of carbon dioxide for extinguishment of methanol could be derived from cup burner test data for e.g. n-heptane (which is the main fuel used in the large-scale verification tests). This was found in several sources, stating MEC values between 20.4 % and 22.0 % [44, 49, 51, 52, 53]. The average value from the five different literature sources was calculated to 21 %. Using this “average MEC value” for n-heptane and increasing it by a safety margin of 18 % (1.22/1.03) according to SBF115:2 [50] gives a MEC for methanol of 24.8 %.

Adding the safety margin of 20 % required by MSC/Circ.848 [41] gives design concentrations according to Table 9. It may be noted that all of the design concentrations calculated in this way are lower than the 40 % required for carbon dioxide systems according to the FSS Code. A lower design concentration is in contradiction to that a higher MEC is required for methanol than for fuels such as diesel and n-heptane. This speaks for a larger safety margin included in the design concentration required by the FSS Code, i.e. when large-scale verification is not required. Assuming that a conventional fixed carbon dioxide fire-extinguishing system is designed based on the MEC for diesel allows calculating the safety margin applied in the FSS Code. Calculations based on heat capacities and data for IG-541 gives a MEC for carbon dioxide to extinguish diesel of 23.7 %. Calculations based on SBF 115:2 give a MEC for carbon dioxide to extinguish diesel of 20.3 %. The 40 % design concentration in the FSS Code hence derives safety margins of 69 % and 97 % for the two calculation methods, respectively. Applying these safety margins to the MEC values for methanol derived by the respective method gives the design concentrations in column “+FSS Code safety margin” Table 9.

### Table 9 MEC values and design concentration for carbon dioxide to extinguish methanol, derived by different methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>MEC</th>
<th>+20 %</th>
<th>+FSS Code safety margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>27 %</td>
<td>32.4 %</td>
<td>-</td>
</tr>
<tr>
<td>Calculated from heat capacity and IG-541 data</td>
<td>30.6 %</td>
<td>36. %</td>
<td>51.7 %</td>
</tr>
<tr>
<td>Calculated from n-heptane data and SBF 115:2</td>
<td>24.8 %</td>
<td>29.8 %</td>
<td>48.8 %</td>
</tr>
</tbody>
</table>

5.3 Water-based fire extinguishment of methanol

The properties of methanol (e.g. low flashpoint, bound oxygen and wide flammability limits) can give reduced possibilities for extinguishment with water. Water extinguishes fire mainly by physical means, by cooling the flame, displacing oxygen and fuel vapour available for combustion, cooling/diluting the fuel and attenuating radiant heat [54]. The dominating mechanism depends on the fuel type, characteristics of the applied water (droplet size, water spray flux, etc.) and the fire scenario (shielding of the fuel, fire size and ventilation conditions, etc.) [55, 56].
5.3.1 Oxygen dispersion and flame cooling

With regards to gas dispersion, this is generally one of the main extinguishing mechanisms of a water-mist system. Reference can be made to the cup burner tests discussed for gas fire-extinguishing systems above. Extinction for several inert gas agents show higher concentrations needed for methanol as compared to n-heptane and diesel [43, 44]. Physical agents such as N\textsubscript{2}, CF\textsubscript{4} [45], IG-55 [46] and IG-541 [47] require about 1.25-1.4 times more agent. Disregarding effects from dilution, surface cooling etc., it can be expected that water-mist, also a physical suppressant, would behave similar to the cited physical agents in the gas phase [45]. This was also demonstrated in small-scale pool fire tests with methanol and heptane where ultra fine water-mist was used as a total flooding agent [45]. The ultra-fine water-mist was not considered to dilute the fuel to any significance but extinguishment was achieved mainly by dispersion and cooling of the flames. The lack of soot in methanol flames minimizes radiation heat losses and reduces the effectiveness of flame cooling, requiring more energy abstraction or extinguishment in other ways. Furthermore, methanol has a lower oxygen index compared to heptane and is relatively less sensitive to the oxygen displacement mechanism by the expanding steam generated by the mist. A relatively longer time was therefore expected for suppression in the small-scale tests with the same water-mist generation rate. The same pool fire pan was used for both fuels (giving 70 kW and 120 kW respectively) and Figure 7 verifies longer suppression time for methanol than for heptane (which is more similar to diesel in this regard e.g. [50]).

![Figure 7](image)

**Figure 7** Methanol and heptane suppression time as functions of mist generation rate [45].

The results from the small-scale fire tests indicate that given the same water application rate, an about 30 % longer suppression time (or 30 % more vaporised water) may be expected. The ultra-fine water-mist has significantly smaller droplets than a traditional water-mist system for total flooding purposes. It therefore behaves more similar to an inert gas. The test results thereby suggest that suppression (by oxygen dispersion and flame cooling) of a methanol fire is more demanding than of a heptane fire.

5.3.2 Surface and flame cooling

For a high flashpoint fuel, such as diesel (flashpoint 58°C), the dominating mechanism when using water-mist is generally cooling of the fuel surface. At the same time as fuel is directly cooled down by water, the water-mist reduces the fire size by minimizing heat transfer from the flame to the fuel. In total, the rate of supply of fuel vapour for combustion is reduced; eventually so much that combustion is not supported in the flame [57]. In the case of the low-flashpoint fuel gasoline (flashpoint -48°C), fire is primarily
extinguished by the water-mist cooling the flame. When the flame is cooled down enough, the result is termination of combustion reactions in the fuel-air mixture. For gasoline this mechanism is dominant over the critical water-mist flux for cooling the fuel surface [58]. This is generally the case for fuels with a boiling point less than that of water [59], including methanol [60].

The effect on the fuel surface temperature during water-mist suppression tests can be illustrated experimentally. As presented in Figure 8, small-scale tests were conducted in a 3x3x3 m well-ventilated compartment with a square fuel pan with the side 0.15 m [57]. They show that the fuel surface temperature for diesel is successively decreased until extinguishment whilst for gasoline it is not decreased until extinguishment. The latter generally corresponds with easy re-ignition [61].

Figure 8  Comparison of fuel surface temperature before and after the application of water-mist (the extinguishing times are 50 s for the diesel fire, 109 s for the gasoline fire and the ethanol fire failed to be extinguished) [57].

The extinguishing effect by flame cooling discussed above for low-flashpoint fuels may although not be as significant for fuels with clean combustion and minimized radiation heat losses from the flames. For example ethanol and methanol produce significantly less soot than conventional fuels. On the other hand they are water-miscible. In the tests presented in Figure 8, the temperature of the ethanol flame decreased quickly right after the water-mist discharge and most of the flames were suppressed. However, there was a small effect on the fuel surface temperature, which stabilized at about 50°C above the ethanol flashpoint (13°C). When water-mist was injected into the ethanol fire, the flames were cooled and the fuel surface layer was diluted by the accumulated droplets, which mix well with the fuel. This resulted in a reduction of fuel vapour available for combustion. After the central flames were put out, fractal flames although appeared around the pool pan edge. This was due to the high temperature pan edge and the lower dilution and water-mist coverage. This resulted in failure of complete extinguishment in the experiments [57]. Hence, a higher application rate would have been necessary to accomplish extinguishment as well as for diesel. In this regard it should be noted that it is expectable that extinguishment would even be less effective for methanol since the smaller amount of soot in the flames make flame cooling less effective.
Similar results were deduced from experiments by Rasbash [61]. He concluded that the extinction mechanism for alcohols is generally reduction in the generation rate of combustible vapour from the liquid (below the value required to support flame). With diesel this reduction primarily occurs by cooling the liquid to the flashpoint and with an alcohol primarily by dilution of the surface layers.

### 5.3.3 Dilution

Low-flashpoint fuels are thus generally harder to extinguish with water-mist than high-flashpoint fuels. The dominant extinguishing mechanism consists in reducing the fuel vapour available for combustion by affecting the fuel temperature to flashpoint relation in different ways. It is demanding to accomplish cooling of the fuel surface to below the flashpoint with water when the fuel is highly volatile and has a low boiling point. For alcohols, in particular methanol, dilution of the surface layer is instead dominant, which increases the flashpoint at the same time as cooling is provided. Extinguishment is achieved when the flashpoint surpasses the temperature of the fuel surface layer. Fuel by obstructions will likely be the most demanding to extinguish. Obstructions reduce dilution and cooling effects and may also heat the fuel (if hot obstructions are in contact with the fuel). In case of a pool fire, re-ignition may occur until the flashpoint has surpassed the fuel temperature in the whole pool. Continued application of foam or water (by fixed systems and manually) is therefore relevant also after a methanol fire has been extinguished. A relatively high auto-ignition temperature (~400°C compared to ~200°C for diesel) makes the fuel less prone to self-ignite but flammable vapours may still be generated, in particular by hot obstructions. Portable foam or water-based fire-extinguishing equipment may be necessary to extinguish some obstructed fires. It should in this regard be noted that water-based systems are not true total-flooding systems in the sense that obstructions affect distribution. In some scenarios, water-mist systems might for example not be able to extinguish all fires, in particular small obstructed fires, regardless of the fuel [62]. If local fires keep the temperature high in a space with volatile fuel as methanol, large amounts of non-combusted fuel vapour may be produced. The auto-ignition temperature of methanol is high but when fuel vapours reach an ignition source (local fire) there is potential for an energetic re-flash/deflagration if sufficient oxygen is available [63]. This risk also applies in case oxygen is let into the space, e.g. at ingress by fire-fighting crew. Routines must therefore be developed for fire patrols with this risk in mind.

Considering extinguishment by dilution, Liaw and Chiu [64] derived a method to theoretically calculate the flashpoint dependence of water diluted methanol, as presented in Figure 9. Small-scale experiments have also been performed which verify that methanol water solutions are flammable to about 65 % volume composition of water at normal room temperature [65]. As a general rule, the Methanol Institute states that methanol is flammable to 75 % dilution by water [66]. Assuming that the fuel has the same temperature as the surrounding space, 75 % dilution corresponds to a room temperature of 35°C, according to Figure 9. Thus, at this temperature a fuel leakage may be ignited unless it is diluted with 75 % water. This seems to be a reasonably conservative assumption for e.g. an engine room. It should be noted that extinguishment by dilution implies that a combustible fuel-water solution may be carried away and spread fire with the drainage until sufficient water has been supplied.
5.3.4 Foam fire extinguishment of methanol

Conventional fire-extinguishing foam will be decomposed if used for a fire in methanol. It is therefore necessary to use alcohol resistant foam for fixed fire-extinguishing systems covering methanol installations. For example foam that is approved in accordance with MSC.1/Circ.1312 [67] or corresponding ISO 7203-3 or EN 1568-4 standards. Alcohol resistant foams complying with these requirements have been tested for acetone and IPA (isopropyl alcohol), which in the development of the test method were proven to be more difficult to extinguish than methanol (initially a DNV method was developed in the ’80s based on [23], including fire tests with acetone, IPA, methyl ethyl ketone (MEK), n-Butyl acetate and methanol; only the first two fuels were included in the further developed test method NT Fire 023 [68] and in the following ISO and EN standards since those fuels in all scenarios were the most difficult to extinguish). Hence, by achieving the fire tests and applicable requirements for alcohol resistant foams in the above referenced standards, such foams can be considered effective for methanol.

Achieving equivalent extinguishment for methanol as of a conventional fuel should thus be possible by use of a foam fire-extinguishing system with alcohol resistant form, approved for machinery spaces of category A. Furthermore, mixing a small concentration of alcohol resistant foam in a water-spraying or water-mist system can improve the effectiveness of such systems for methanol.

5.3.5 Large-scale tests with a water mist fire-extinguishing system

Tests have been performed to further investigate the effects of a conventional water mist fire-extinguishing system on a methanol fire. A system approved according to MSC/Circ.1165 was used in the tests. However, the tests did not follow the standardized test procedure and therefore reference tests were carried out with diesel for comparison. The test compartment was (W×L×H) 9×9×2.6 m and a pool fire tray was used at the centre, measuring 1.25×1.25 m. Tests were carried out with diesel and methanol, with open and closed doors to the test compartment, i.e. a total of four tests. Tests were
performed with the doors open since this is prescribed in the test standard and with the doors closed since that is the most probable case for an engine or pump room.

Extinguishment in tests according to MSC/Circ.1165 is achieved as a fine balance between the amount of water-mist, ventilation openings and the heat produced by the fire. Too much water makes the space too cold and prevents sufficient vaporisation of water (and oxygen displacement) which generally is the primary means for extinguishment. For the same reason, too large openings prevent extinguishment since oxygen levels are not sufficiently reduced. Naturally, a too large fire will although be impossible to quench.

The fire tests with diesel showed that an approved water-mist fire-extinguishing system would most likely extinguish a large diesel fire swiftly if doors to the compartment are open. However, the diesel fire in the tests was not sufficiently large to produce enough water vapour for extinguishment, as shown in Figure 10. When the doors were closed, extinguishment was achieved within 5 minutes.

![Figure 10. Average compartment temperatures in suppression tests with water-mist.](image)

Extinguishment of a methanol fire seemed more demanding since the fire produced relatively little heat, and thereby water vapour. The tests showed that the suppressing effect on the methanol fire, provided by flame cooling, was sufficient to leave only small flames burning along the edges of the fuel pan. This may be compared with the ethanol test results in [57]. Heat was provided by the fuel pan edges and they also cause reduced coverage by the system. Furthermore, the tests showed that even if a water-mist system will not fully extinguish a methanol fire, temperatures in the compartment will be kept sufficiently low to prevent damage and allowing for evacuation and unhindered firefighting. The temperatures in the methanol tests were comparable with the temperatures in the diesel tests at or close to extinguishment. Furthermore, there was no smoke production observed in the methanol tests; only water-mist was visible at door openings. The conclusion from the tests was therefore that an approved water-mist system would suppress a methanol fire to a point where damage to equipment will be prevented and evacuation and manual firefighting can be managed. Nevertheless, if extinguishment is desired the system needs be combined with a system capable of removing or extinguishing formed methanol pools (e.g. by a high-expansion foam fire-extinguishing system or drencher dilution system in the bilge).
5.3.6 Conclusions on water-based extinguishment of methanol

The dominant extinguishing mechanism for methanol consists in dilution of the surface layer. An ultra-fine water-mist system, giving practically no dilution effect, showed that flame cooling is not an as effective extinguishing mechanism since methanol has minimal radiation heat losses from the flames. This was also showed from small-scale tests, where a fuel with clean combustion was not affected by flame cooling. Nor was it affected by surface cooling, due to its low flashpoint. The effect from oxygen dispersion in extinguishment with water-based systems is neither as effective, as also concluded for inert gas systems. Large-scale tests have been carried out which show results in line with these conclusions. Thus, methanol is more difficult to suppress and extinguish than conventional fuels. The primary extinguishing mechanism is dilution of the fuel surface layer, which could be assisted by a high water application rate. It is possible that extinguishment can be more effectively accomplished by other means than with water mist, e.g. with water spray. It is also possible that more effective extinguishment can be achieved by mixing a small amount of alcohol resistant foam in such a system. Fuel by obstructions will likely be the most demanding to extinguish since they reduce dilution and cooling effects and may also heat the fuel and increase fuel vaporisation. Even if extinguishment is not achieved, the large-scale tests showed that a water mist fire-extinguishing system can keep gas temperatures low and protect surroundings by cooling.

5.4 Fire extinguishment of LNG

Special requirements for fire extinguishing systems for LNG installations are only given for open deck, as discussed in Section 3.2. The focus in the IGF code seems to be to mitigate the consequences of a fire by protecting the tank and the bunker station, which both could generate a larger fire. The tank and surrounding boundaries shall be protected by a water-spraying system and the bunker station by a water-spraying system and a fixed dry powder fire-extinguishing system. For interior spaces, for example the engine and pump rooms, there are no special requirements for extinguishing an LNG fire. The general principle appears to be to prevent leakage, both in interior spaces and on open deck.

Additional guidance on LNG fire safety and fire mitigation is given in e.g. Recommended practice - Development and operation of liquefied natural gas bunkering facilities from DNV-GL [69] and in NFPA 59A: Standard for Production, Storage, and Handling of Liquefied Natural Gas (LNG) [70], which contains requirements on fire extinguishment and fire control systems and equipment.

Detailed information on fire risks with LNG and guidelines on fire-fighting can be found elsewhere, e.g. in Natural Gas Engineering and Safety Challenges by Nasr and Connor [71] and LNG Fire Protection and Emergency Response from BP [72]. Much of the experimental work for formulating guidelines for LNG fire mitigation have been made at the experimental facilities of the Texas A&M University’s Emergency Service Training Institute (ESTI), sponsored by BP [73]. There have been several test programmes conducted on LNG fire mitigation and extinguishment, however, the industry has not come together to issue definitive fire control test criteria and recommendations [74].

In the case of a LNG release, the fuel would immediately start to boil-off (see Section 2 for LNG properties) forming a visible white cloud from condensation of ambient water vapour. In case of ignition, the cloud will rapidly be consumed by the fire and flash back to the source of the leakage. If a pool of LNG is formed, the rate of heat release will increase by the heat generated from the fire. The best way to stop this type of fire is by
removing the fuel source [71]. The firefighting of a LNG release fire will often be conducted with the aim of controlling the fire rather than extinguishing the fire [75]. Water spray application is used for protecting surrounding objects from heat affected exposure and to mitigate unignited gases, high expansion foam is used for reducing the fire size and dry powder may be used for extinguishment [76]. Foam glass has been investigated as an alternative or supplement to high expansion foam application [77].

General recommendations from [76] on fire mitigation actions for different LNG fire scenarios are summarized below. In the subsections below, details are also given for the different recommended fire mitigation methods, namely water spray application, high expansion foam, foam glass and dry powder.

5.4.1 Fire mitigation strategies

Incident scenarios and mitigation tactics for release of LNG and fire in processes, shipping and storage are given in [76]. The general tactics outlined could be transferred also to potential incidents with LNG fuelled ships and are outlined below. Three general types of scenarios are identified; unignited gas release, jet fires and pool fires.

Gas release would be possible from transfer/pumping processes, tank incidents and leakages accumulated in containment pits. For unignited gas release the mitigation tactics should consider:

- Water spray curtains to dilute and divert gases (but water must be avoided in a LNG pool as it accelerates the evaporation rate);
- Portable detection for gas drift to possible ignition sources;
- Portable detection for gas drift to semi- or full-confined areas where an explosion is possible;
- Use of high expansion foam for vapour reduction from LNG pool.

Jet fires are possible from transfer/pumping processes and leakages in transfer pipes. The mitigation tactics for jet fires should consider:

- Isolation of pressure source (shut off if possible);
- Prioritise cooling;
- Cool any flame affected boundary objects;
- Cool any radiant heat affected objects;
- Dry chemical powder may extinguish a jet fire – but (important) – a combustible gas cloud will remain.

A pool fire is a possible scenario in case of larger releases or accumulation of smaller releases in containment pits. The mitigation tactics for pool fires should consider:

- Cool any heat or flame affected boundary objects;
- Avoid water in the burning pool;
- Use of high expansion foam to reduce fire size (radiant heat reduction);
- Dry chemical can be used – but (important) – a combustible gas cloud will remain;
- A combination of fixed foaming to reduce the fire; and dry chemical for extinguishment, or, dry chemical fire knock down and foaming thereafter to reduce vaporisation.
5.4.2 Water-spray application

Water spray is recommended for protection (cooling) of boundary objects from radiant heat but could also be used for LNG vapour control. In both cases it is important that water does not come in contact with the LNG liquid itself, as the water will heat the cryogenic liquid and thus increase the rate of vaporisation, which as a consequence increases the fire intensity [74]. As described in section 3, the IGF code requires to install water spray systems covering a tank on open deck, surrounding boundaries and bunker stations. It is although important that such systems are NOT activated upon a LNG release or fire. Such systems should only be activated as an additional protection of the tank and bunker station from other types of fires.

The use of water spray curtains to disperse LNG vapour clouds has been investigated and this research indicates that the action of water sprays reduced the LNG concentration as well as pushed the vapour upward [78]. There are however weaknesses in the use of vapour curtains to minimize vapour migration [74], e.g., that the water spray nozzles normally used by the fire department often will have gaps at the interface between the ground and the lower part of the curtain, and it is here that could vapours may pass.

5.4.3 Dry chemical powder fire-extinguishing system

LNG fires can be extinguished using dry powder and is prescribed in e.g. the IGF code to be installed at bunker stations. What should be considered is firstly that there is enough extinguishing media available so that it can be applied correctly; and secondly that the subsequent vaporisation of remaining LNG will not create a greater hazard [74]. Recommendations on the use of dry powder are given in [71] and are summarized below:

- From danger of re-ignition, dry powder should not be used unless the source of gas can be isolated;
- Maximum possible application rate should be used at once so that reserves are not wasted and successful extinguishment is obtained;
- Coordinated simultaneous attack with all available applicators, if possible from windward (if outside), will have maximum effect;
- Powder jets should be aimed with the object of reducing boil-off rate by sweeping the whole fire area, but the pool must not be agitated.

The dry chemical powders used for LNG are generally based on sodium or potassium bicarbonate [75], and systems approved for marine applications are commercially readily available, e.g. [79].

5.4.4 High expansion foam

Use of high expansion foam (HEX) is the primary accepted method to mitigate a LNG pool fire. This is although not a requirement for the bunker stations or tanks on ships according to the IGF code. Application of the foam will form a barrier which prevents the radiation from the flames to the liquid below and reduces thus the vaporisation rate and the extent and radiation of the fire. The foam should be continuously applied and a foam depth of 1-2 m should be achieved [71]. HEX of an expansion rate of 500:1 has been found to be the most effective [71]. Low and medium expansion foams contain too much water which warms the LNG liquid and thereby increases the vaporisation rate with intensified burning as result [74].

Recommended application rates of high expansion foam have been experimentally determined in tests by BP and Texas A&M Emergency Service Training Institute [73][80]. Practical foam application rates of 10 l/min/m² was determined effective on
fires in concrete LNG containment pits when LNG Turbex foam generators and Expandol high expansion foam concentrate at 3% induction rates were used. This was obtained by applying a safety factor of 3 on the minimum effective experimental effective application rate. The fire control time was defined as the time required for reaching a 90% reduction in heat radiation [80].

5.4.5 Foam glass

Foam glass has been raised as an alternative or complement to high expansion foam. Foam glass or cellular glass is generally available as scrap material. The foam glass is available in different forms and has its applications as insulation material. There is a commercial product, Foamglas®, which is intended for use as a non-flammable load-bearing material and has been evaluated for the use in fire control of LNG pool fires [80].

The use of foam glass as a firefighting method, instead of traditional foam application, would be to avoid the deficiencies of the latter, such as [80]:

- The need for vast dry chemical amounts to ensure complete extinction after being controlled by HEX. Incomplete application of dry chemical might lead to the re-establishment of the pool fire;
- The unsuitability of low expansion foam to fight LNG fires;
- Only some types of foam such as HEX are suitable to control larger LNG fires. However, HEX is deteriorated by the fire which means that continuous application is needed. This requires a very high capacity foaming system;
- Further, HEX systems are active systems that involve an activation system that might cause a delay of application.

Suardin [80] concludes from the testing of Foamglas® PFS [77] that it was able to suppress a LNG pool fire, and that it provides the following benefits:

- Foamglas® PFS had a performance comparable with to continuous application of expansion foam (at an application rate of 10 l/min/m²);
- The consistent coverage provided by Foamglas® PFS stabilized the fire with no observed fluctuations. It has the advantage that it does not depend on any additional procedure or supplemental application during the fire.

It is recommended by Suardin [80] to install both expansion foam and Foamglas® in order to achieve maximum protection during LNG vapour dispersion and LNG pool fire. The recommendation is based on an application for an LNG containment pit.

5.4.6 Conclusions on fire extinguishment of LNG

The field of LNG fire mitigation has some history and the use of LNG as bunker fuel can benefit from this work. The findings in the literature discussed above show that the general tactics in the fire-fighting of a LNG release fire generally is to control rather than to extinguish the fire. Active fire-fighting methods are water spray application for protecting from heat-exposure and to mitigate spread of unignited gases. This is required in accordance with the IGF code but it is important that such systems are not activated upon a LNG release or fire since that would intensify the vaporization rate and hence the fire. Such systems should only be activated as an additional protection of the tank and bunker station from other types of fires.

High expansion foam can be used for reducing the fire intensity (radiation towards the pool surface and thus the vaporization rate) of pool fires and could be very relevant, e.g., for bunker stations on ships. There is although no such requirement in the IGF code. Dry
Powder is although required at bunker stations and can be used for extinguishment but requires a suitable procedure. Although much experimental work has been done over the years, there are no easily available compilations of detailed extinguishing procedures on dry powder, including e.g. application rates etc. Possibly this information is available with commercial actors such as fuel producers and fire mitigation system providers.
Conclusions on hazards and implications for detection and extinguishment

There are new hazards introduced with LFFs, not only from the low flashpoint, but also from other specific properties as can be conceived from the comparison of properties in sections 2.2 and 2.3. These properties influence the fire behaviour which was discussed in section 2.4, and they also influence the possibility for detection (section 4) and the suitable methods for extinguishment of fire (section 5).

The hazards identified from the literature study presented above and from the HazId workshop are summarised in section 6.1. The potential implications for detection and extinguishment are also presented.

The implications on detection and extinguishment form a need of experimental studies to ensure that safety is achieved by active fire protection systems. Proposed testing and verification needs are given in section 6.2.

6.1 Hazards from LFFs

The properties of methanol identified to pose new hazards, compared to traditional marine fuel oils, that have potential implications for detection of fuel vapour leakage/fire atmospheres or implications on the effectiveness or choice of extinguishing method are summarized in Table 10.

<table>
<thead>
<tr>
<th>Property of Methanol</th>
<th>Hazard compared to marine fuel oils</th>
<th>Potential implications for detection/extinguishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low flashpoint</td>
<td>• The liquid fuel is always ignitable at room temperature • Fuel vapour may accumulate and reach LEL at room temperature</td>
<td>• Cooling by water less effective • Need for gas detection</td>
</tr>
<tr>
<td>Flammability limits and range</td>
<td>• Burns in a wider flammability range</td>
<td>• The wide range is negative for extinguishment, but a higher concentration (LFL) is required for combustion</td>
</tr>
<tr>
<td>Contains oxygen in the molecule</td>
<td>• Can burn at lower ambient oxygen levels</td>
<td>• Higher extinguishing concentrations might be needed for gas extinction systems</td>
</tr>
<tr>
<td>No soot production, clear/blue flame</td>
<td>• “Invisible flame” • No smoke</td>
<td>• Negative for manual detection by observation • Negative for smoke detection • IR flame detectors must be adapted for the radiation spectrum present</td>
</tr>
<tr>
<td>Soluble in water</td>
<td>• Extinguishing hazards (see next column)</td>
<td>• Requires high water application rates to dilute the fuel for extinguishment (which is the main extinguishing mechanism) • Require alcohol-resistant foam</td>
</tr>
<tr>
<td>Vapour density</td>
<td>• Slightly higher vapour density than air can give accumulation in low points</td>
<td>• Could be advantageous for local leak detection but also sets more demands on the location of the detector</td>
</tr>
</tbody>
</table>
The properties of LNG identified to pose new hazards, compared to traditional marine fuel oils, that have potential implications for detection of fuel vapour leakage/fire atmospheres or implications on the effectiveness or choice of extinguishing method are summarized in Table 11.

Table 11  Hazards from LNG and implications on detection/extinguishment.

<table>
<thead>
<tr>
<th>Property of LNG</th>
<th>Hazard compared marine fuel oils</th>
<th>Potential implications for detection/extinguishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low flashpoint</td>
<td>• The fuel is a gas and always ignitable at some location  • Ignition of a leakage can result in an deflagration or explosion if in confined space</td>
<td>• Strong need for gas detection</td>
</tr>
<tr>
<td>Auto ignition</td>
<td>• Higher auto-ignition temperature but likely to reach hot surfaces</td>
<td>• Local gas detection in the proximity of potential hot surfaces</td>
</tr>
<tr>
<td>Low boiling point</td>
<td>• Minor-moderate fuel leakages will directly evaporate to gas phase  • Large releases of fuel will create a fast evaporating pool</td>
<td>• Strong need for gas detection  • Water increases vaporization of LNG  • Drainage of foam increases vaporization of LNG</td>
</tr>
<tr>
<td>Efficient combustion</td>
<td>• Low soot production</td>
<td>• Negative for smoke detection</td>
</tr>
</tbody>
</table>

6.2  Need for testing and verification

The specific properties of LFFs that differ from traditional marine fuel oils identified above have potential implications on detection and extinguishment. These need to be identified, quantified and solutions proposed for safe systems. Proposed testing and verification needs are given below.

6.2.1  Gas and fire detection

In order to determine what detection methodologies and technologies that should be recommended for LFFs and how the detection systems used today should be modified, testing must be performed. Below are discussed potential tests that should be considered.

Gas detection tests
A gas detector designed to detect a specific substance should also be approved by a suitable standard to verify the application. According to the regulations, a simulation or test for each specific case is needed to come up with good positions. However, not only the airflow is important but also density of the fuel vapour and vaporisation velocity. This could be simulated as well, but there is a need for verifying tests.

Verification tests should be carried out with consideration to realistic room size, ceiling height, airflows and ventilation outlets and inlets. A pool of methanol or an effluent of LNG should be monitored by measuring gas/vapour concentration at several positions in the room, including both low and high positions as well as in ventilation outlets. However, the explosion risk that occurs when filling up a large room with flammable gases without initiating a fire is of concern, and can be a reason to not conduct such tests.
Fire detection tests
Several different tests are of interest regarding fire detection. Focusing on methanol fires, verification tests should be carried out to show that approval standards for flame detectors such as EN 54-10 and ISO 7240-10 actually ensure good detection of a methanol fire (the relevant test fire used according to these standards comes from burning methylated spirit). These standards also have methods to determine e.g. sensitivity and field of view, which is needed for guidance in distribution of such flame detectors.

Furthermore, a comparison test with different detection technologies would give information on advantages and disadvantages of different systems. Potential systems to be tested are different types of flame detectors, very sensitive heat detection (such as fibre optic systems), thermal imaging systems and gas detection (for fire). Depending on what different systems that will be tested, the setup can be adapted. For example, if only flame detectors are tested, the fire could be in an open space, but if also a gas detection system is included the setup must be a realistic room scenario. It is important to test against both open fires and partly hidden fires, since hidden fires are of more concern for some systems than others.

At last, considering a LNG fire it should be tested if a conventional smoke detection system could detect such a fire. A large pool fire of LNG has been shown to produce significant amounts of soot [33]; however, it should be tested if the soot production from small fires is also enough to trigger a smoke alarm.

6.2.2 Fire extinguishment

Testing and verification for methanol fires
A test programme for methanol needs to include both fundamental studies to characterize the fuel and comparative large-scale tests with extinguishing systems for verification.

A series of methanol pool fires of relevant sizes are proposed, in order to measure the heat release rate, fuel mass flux and heat flux balance (radiative and conductive part). These parameters are of interest, but also necessary for any additional comparative large-scale tests. Large-scale tests should also be used for the measurements of parameters relevant for fire detection (see section 6.2.1).

Large-scale fire tests with water spray or mist systems (local application). The fire extinguishing mechanism for water spray or water-mist system is a combination of dilution, flame cooling and surface cooling. The tests should focus on comparing the effectiveness of different systems on diesel and methanol pool fires. The extinguishment of methanol spray fires may be less relevant to study, as modern fuel system will limit the possibilities for long duration spray fires.

Large-scale fire tests with water mist systems (total compartment systems). It is suggested that fire tests are conducted inside a reasonably large test compartment with exposed or shielded diesel and methanol pool fires. The objective of the tests should be to compare the time until fire extinguishment, gas temperatures, etc. using fires with the same nominal heat release rate or alternatively the same pool area.

Large-scale verification tests for bilge foam systems (total compartment systems). This type of system is proposed in the draft code but its performance has not been verified for alcohol resistant foams.

Small-scale fire tests with extinguishing gas agents. Determination of design concentrations for gas fire-extinguishing systems (cup burner or REMP tests) is
suggested. Large-scale fire tests with gas fire-extinguishing systems are considered of secondary importance as such tests primarily determine proper distribution of the agent inside the compartment. Instead, focus should be to determine the minimum gas design concentration for different agents, as a first step.

Testing and verification for LNG fires
The safety concept in the IGF code for LNG is to limit the possibility of a release within the ship. If a leakage would nevertheless occur it is managed by gas detection and shut-off mechanisms of fuel transfer. Furthermore, a limited release of liquid or vaporized natural gas is ventilated to reduce concentration of fuel vapour and to avoid an ignitable atmosphere.

However, there are no requirements for systems to extinguish an interior LNG fire. There are thus no regulatory incentives to study the effectiveness of extinguishing systems for LNG compartment fires. Specific fire extinguishing requirements for LNG are only given for powder systems at bunker stations.
7 References


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[17] IEC 60 079-12, Classification of mixtures of gases or vapours with air according to their maximum experimental safe gaps and minimum ignition currents.

[18] IEC 60 079-4, Method of test for ignition temperature.

[19] ASTM E582, Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures.


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Appendix A  IMO tests for fixed fire extinguishing systems

A.1 Total flooding fire-extinguishing systems

Machinery spaces of category containing internal combustion machinery shall be provided with a fixed fire-extinguishing system. Any of the three following types of systems may be used:

1. a fixed gas fire-extinguishing system;
2. a fixed high-expansion foam fire-extinguishing system; or
3. a fixed water-spraying fire-extinguishing system.

The FSS Code also allows different equivalent fixed fire-extinguishing systems, such as water mist systems, high-expansion systems using inside air or fixed aerosol fire-extinguishing systems. The test requirements for the alternative total flooding systems are briefly summarized below.

Fixed gas fire-extinguishing systems

The specific fire test procedures are given in MSC/Circ.776 as amended by MSC/Circ. 848 and MSC/Circ. 1267, EQUIVALENT FIXED GAS FIRE-EXTINGUISHING SYSTEMS. The fire tests are conducted inside a fully enclosed 500 m$^3$ test compartment. For gaseous agents where the design concentration has already been established, tests are conducted with a concentration of gas equal to 77% of the design concentration (typically established using small-scale cup burner tests). Small test fires (‘Tell-tales’) are positioned at the eight corners of the test compartment, in order to verify that gas is properly distributed to all parts of the compartment and able to provide fire extinguishment. This particular test can therefore be considered a test of both the gas properties and the system hardware and design, e.g. the coverage area of the nozzles and their ability to evenly distribute the gas. The Tell-tale fires should be extinguished no later than 30 seconds after the end of the discharge. It should be noticed that there are no re-ignition sparks above the Tell-tale fires, as is the case during the tests for fixed aerosol fire-extinguishing systems.

Combinations of large diesel and heptane pool/spray and wood crib fire scenarios are used for gaseous agents where the design concentration has not been established.

The test procedures are applicable for both halogenated agents, typically having short discharge times as well as for inert or blend or inter gases, typically having longer discharge times.
Figure A-1  A test compartment used for testing of fixed gas fire-extinguishing systems.

**Fixed high-expansion foam fire-extinguishing systems using inside air**  
The specific fire test procedures are given in MSC.1/Circ. 1271 as amended by MSC.1/Circ.1312, HIGH-EXPANSION FOAM SYSTEMS USING INSIDE AIR. These types of high-expansion foam systems have the foam generators positioned inside the protected compartment and foam is generated without fresh air from the outside. As the production of foam is influenced by the ventilation conditions, the gas temperatures inside the compartment, fuel vapours, etc., fire tests are conducted over a range of compartment sizes:

- Test compartment no.1: Volume of 500 m$^3$ with 4 m$^2$ doorway opening.
- Test compartment no.2: Volume between 1200 m$^3$ and 3500 m$^3$ with a 4 m$^2$ doorway opening.

The fire test scenarios consist of combinations of diesel pool and spray fires and the overall time to extinction should not exceed 15 minutes. At the end of discharge of foam there should be no re-ignition or fire spread.

The objectives of the tests are primarily to determine the foam filling rate (m/s) and the number of generators required for a certain volume.

**Fixed water-spraying fire-extinguishing systems**  
The specific fire test procedures are given in MSC/Circ. 668 as amended by MSC/Circ. 728, MSC/Circ. 1165, MSC/Circ. 1237, MSC/Circ. 1269 and MSC/Circ. 1386, REVISED GUIDELINES FOR THE APPROVAL OF EQUIVALENT WATER-BASED FIRE-EXTINGUISHING SYSTEMS FOR MACHINERY SPACES AND CARGO PUMP-ROOMS. Systems meeting the objectives of these tests should be considered as ‘equivalent’ to halon systems and not ‘equivalent’ to water spraying systems. However, it should be observed that the maximum allowed time to fire extinguishment is 15 minutes, which typically is much longer than that of a gaseous agent.
Tests shall be conducted inside a test compartment at having a volume of at least 500 m$^3$. The test compartment is fitted with a 4 m$^2$ doorway opening. Typically, manufactures test their systems in compartments that are much larger in size. There are a number of different diesel and heptane pool/spray fire scenarios that need to be extinguished within 15 minutes of discharge. In one test, a heptane pool fire is combined with a small wood crib, acting as a re-ignition source. In addition to the fire scenarios required to be extinguished, there is a ‘thermal management’ test, consisting of a heptane pool fire. The pool fire size is increased with the volume of the test compartment and the intent is that the system should limit the gas temperature to below 100°C, no later than five minutes after the start of the discharge.

![Figure A-2](image)

(a) (b)

Figure A-2 Tests with a fixed water-spraying fire-extinguishing system; (a) the engine mock-up; (b) a heptane pool fire in the test compartment.

**Fixed aerosol fire-extinguishing systems**

The specific fire test procedures are given in MSC/Circ.1007 as amended by MSC.1/Circ.1270, REVISED GUIDELINES FOR THE APPROVAL OF FIXED AEROSOL FIRE-EXTINGUISHING SYSTEMS EQUIVALENT TO FIXED GAS FIRE-EXTINGUISHING SYSTEMS, AS REFERRED TO IN SOLAS 74, FOR MACHINERY SPACES.

The fire tests are conducted inside a fully enclosed 500 m$^3$ test compartment. The fire test scenarios consist of combinations of either:

- Small test fires (‘Tell-tales’) positioned at the eight corners of the test compartment. Heptane pool fires.
- A diesel pool fire, a wood crib fire, a low-pressure spray fire and polymeric sheets.
- A large diesel pool fire.

The Tell-tale fire test is required to evaluate new nozzles and related distribution system equipment (hardware) for systems employing fire extinguishing media that have successfully passed all the other fire tests. This test should be used to establish and verify the manufacturer’s minimum nozzle design pressure. For this particular test, the agent concentration should be not more than 77% of the manufacturer’s recommended design application density. The fires should be extinguished within 30 seconds after completion of discharge and during a 15 minute hold time, attempts should be made to re-ignite the fires using spark igniters.

For the tests involving the wood crib, the pre-burn time should be either 2, 4 or 6 minutes. The maximum allowed weight loss of the wood crib should be 30%, 50% and 60%, respectively; however, complete fire extinguishment is not required.
A.2 Local application fire-extinguishing systems

For passenger ships of 500 gross tonnage and above, and cargo ships of 2000 gross tonnage and above, machinery spaces of category A, in excess of 500 m$^3$, shall in addition to a ‘total flooding system’, be protected by an approved type of water-based or equivalent fixed local application fire-extinguishing system.

Local application fire-extinguishing systems shall comply with the installation guidelines, component tests and fire test procedures in MSC/Circ.913, as amended by MSC/Circ.1082 and MSC/Circ.1387, REVISED GUIDELINES FOR THE APPROVAL OF FIXED WATER-BASED LOCAL APPLICATION FIRE-FIGHTING SYSTEMS FOR USE IN CATEGORY A MACHINERY SPACES (MSC/CIRC.913).

When tested, a system consisting of a nozzle grid of either 2×2 or 3×3 nozzles should provide extinguishment of light diesel oil fuel spray fires. Two scenarios are used, one spray fire having a nominal heat release rate of 1 MW and one having a nominal heat release rate of 6 MW. The spray fires are positioned at different positions relative to the nozzles, either directly under one nozzle, between two nozzles or between four nozzles. The test method is intended to evaluate the maximum nozzle spacing, the minimum and maximum distance from the nozzle to the hazard, the minimum nozzle flow rate and nozzle angle, if any, in addition to the minimum operating pressure.
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