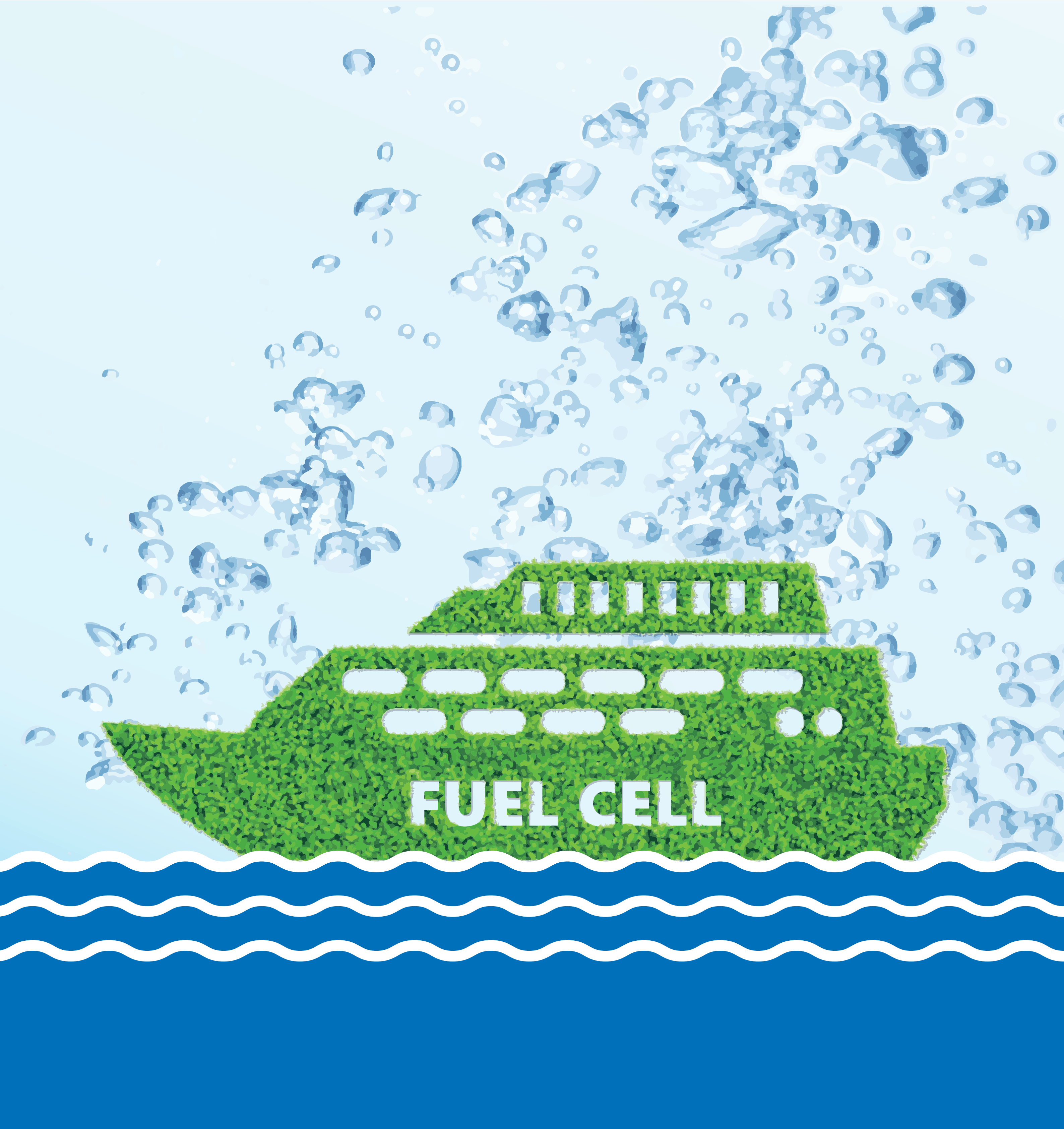
CHARTING THE FUTURE

ClassNK

Guidelines for Fuel Cell Power Systems On Board Ships [Second Edition]

[English]



Introduction

In recent years, the environmental regulations for ships are getting stricter. At the 72nd session of the Marine Environment Protection Committee (MEPC72) held in April 2018, the IMO adopted the MEPC.304(72) INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS that includes reduction targets for greenhouse gas (GHG) emissions as well as candidate measures to achieve them. One of the medium-term targets is to reduce the total annual GHG emissions from international shipping by at least 50% by 2050 compared to 2008. In order to achieve the target, the introduction of alternative fuels and technological innovation is integral. In addition, at the 80th session of the Marine Environment Protection Committee (MEPC80) held in July 2023, the "2023 IMO Revised GHG reduction strategy" was adopted, incorporating newly strengthened GHG reduction targets including zero of GHG emissions by around 2050. [1][2]

Fuel cells are power systems that use electrical energy obtained from the chemical reaction of hydrogen and oxygen, which produces water and electricity. Because fuel cells do not produce carbon dioxide during the process of generating electricity, they are expected to provide promising ways to comply with the GHG regulations. The practical use of fuel cells has been on a plateau mainly due to high costs. In Germany, where a nationwide hydrogen infrastructure is in place, fuel cell buses are already in operation. In Japan, fuel cell cars using high pressure hydrogen as fuel have been commercially available since 2014. In relation to ships, there are use cases for water buses and small excursion boats sailing on rivers in Europe. In addition, there are plans to use fuel cells for auxiliary power supply and main propulsion of large cruise ships. [3]

Fuel cells require the handling of hydrogen, which has many physical properties that are different from those of conventional fuel gases. To ensure safety, it is critical to take sufficient measures. As for safety provisions for the use of fuel cells onboard ships, there are ongoing discussions in the IMO regarding amendments to add related provisions to the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code), which defines safety provisions for ships using gases. At the 5th session of the Sub-Committee on Carriage of Cargoes and Containers (CCC 5) held in September 2018, the Sub-Committee agreed to develop interim guidelines summarizing the safety provisions for fuel cells as a preliminary step toward the amendments to the IGF Code. [4]

In response to the situation, in March 2019, ClassNK decided to publish the first edition of its own guidelines summarizing information related to fuel cells and incorporating the interim guidelines of the IMO, titled, the "Guidelines for Fuel Cell Systems On Board Ships," aimed at assisting in the design of fuel cell systems for ships.

Subsequently, at the 105th Maritime Safety Committee (MSC 105) held in April 2022, as a part of long term consideration on amendments to IGF Code, the interim guidelines for the safety of ships using fuel cell power installations were approved, and MSC.1/Circ. 1647 was issued. Accordingly, MSC.1/Circ. 1647 was incorporated into these guidelines, and Edition 2 of the Guidelines for Fuel Cell Systems On Board Ships was published with the addition of an Annex compiling requirements related to fuel cell power systems, which were extracted from relevant IEC standards and regulations. In Edition 2, it was decided that appropriate notation will be affixed to the classification characters for ships complying with the Guidelines.

Chapter 1, Part A of the Guidelines describes the types and characteristics of fuel cells as general information related to fuel cells. Chapter 2, Part A describes the comparison of the physical properties of hydrogen and conventional fuel gases from the standpoint of safety. Chapters 1 to 5, Part B summarize MSC.1/Circ. 1647 with the added requirement of notation affixed to the classification characters of the ship, and comments by ClassNK as Design Requirements for Ships Powered by Fuel Cells. Specific requirements for fuel cell power systems, including plans and documents to be submitted and tests to be carried out, are described in the Annex. MSC.1/Circ. 1647 (Interim Guidelines for the Safety of Ships using Fuel Cell Power Installations) is attached as the Appendix.

The Guidelines provide proposed design requirements as of this moment and will be reviewed periodically to take into consideration the future progress of the review by the IMO and rapid development of new technologies.

Revision History

No.	Date	Part	Details of revision
1	June 6, 2019	-	First issue
2	September 29, 2023	Chapters 1 and 2, Part A	Chapters 1 and 2 of First edition were reviewed
		Part B	Chapter 3 of First edition were reviewed based on MSC.1/1647
		1.1.2 and 1.1.3, Part B	Requirement for class notation was added
		Annex	Requirement of plans, documents and tests for fuel cell power system were added
		Appendix	MSC.1/1647 was attached

Guidelines for Fuel Cell Power Systems On Board Ships

CONTENTS

Part A TECHNICAL GUIDANCE FOR FUEL CELL TECHNOLOGY

Chapter 1 GENERAL

This chapter describes the overview of the types, principles, characteristics, and major applications of fuel cells.

1.1 Types and Principles of Fuel Cells

A fuel cell is electrochemical cell that converts chemical energy of a fuel into electricity through electrochemical reactions of a fuel (such as hydrogen) and an oxidant (such as oxygen). While common batteries use the chemical energy from chemical substances that are already present in them, fuel cells sustain the chemical reactions by continuously feeding fuel and oxygen (usually from the air). Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied.

Most fuel cells mainly utilize electrical energy from the reverse reaction of electrolysis of water, i.e. $2H_2 + O_2 \rightarrow 2H_2O$, to produce electricity. When a fuel other than hydrogen is used in a fuel cell that uses hydrogen as fuel, a device called a reformer is used to produce hydrogen from the fuel and feed it to the fuel cell.

The fuel cell market is growing, and there are a variety of fuel cells that use different types of electrochemical reactions and electrolytes. Some of the fuel cells that are advantageous in terms of efficiency are provided below as examples. Table 1 summarizes the characteristics of major fuel cells. [5]

1.1.1 Alkaline fuel cell (AFC)

Alkaline fuel cells (AFCs) are one of the earliest types of fuel cells. They are famous for being used in NASA's Apollo missions. In the missions, not just electricity, but water and heat, the by-products of electricity generation, were also used. The Hydra, the world's first fuel cell passenger boat, was powered by a 5kW AFC. [3]

The operating temperature of AFCs is 20-150°C, and their efficiency is approximately 60-70%.

The AFC usually consists of a nickel anode, silver cathode, and alkaline electrolyte. AFCs use an aqueous alkaline solution (such as potassium hydroxide) as the electrolyte. The fuel is hydrogen, and the oxidant is oxygen. Hydroxide ions travel from the cathode to the anode through the electrolyte. Pure hydrogen and oxygen must be used to prevent the alkaline electrolyte from degrading as a result of reacting with carbon dioxide.

The major reactions that occur are as follows.

Anode: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$
Cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
Overall Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

1.1.2 Polymer electrolyte fuel cell (PEFC)

Polymer electrolyte (membrane) fuel cells (PE (M) FCs) are used in automobiles and as the residential fuel cells called "ENE-FARM." As part of the Zero Emission Project, small ships using PEFCs are built in Germany. [3]

The operating temperature of PEFCs is 50-100°C, and their efficiency is approximately 30-44%. The operating temperature of PEFCs is rather high (reported to be 120-200°C) because they use polybenzimidazole (PBI) as the electrolyte. [6]

PEFCs use a platinum catalyst in the electrodes, and use polymer membranes (ion exchange membranes), which are electrically insulating but conduct hydrogen ions, as the electrolyte. The fuel is hydrogen, and the oxidant is oxygen. A fuel other than hydrogen can be used after reforming. However, it is essential to remove carbon monoxide from the reformed fuel because the platinum catalyst degrades due to carbon monoxide in the reformed fuel. Cost reduction is difficult because of the use of platinum. Research to use cobalt and nickel as alternative catalysts to platinum is underway. [7]

The major reactions that occur are as follows.

Anode: $2H_2 \rightarrow 4H^+ + 4e^-$
Cathode : $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Overall Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

1.1.3 Direct methanol fuel cell (DMFC)

Direct methanol fuel cells (DMFCs) are a type of direct fuel cells (DFCs), which use a fuel directly fed to fuel cell stacks without a reformer, in which methanol is used as the fuel. Other types of DFCs use ethanol, diethyl ether, etc. as the fuel.

The operating temperature of DMFCs is 50-120°C, and their efficiency is approximately 10-25%. The cell efficiency may be increased by operating at higher temperatures and pressures, but these conditions result in a higher total loss in the system.

DMFCs use polymer membranes (ion exchange membranes) as the electrolyte, and use a platinum-ruthenium catalyst, which can directly use hydrogen in methanol, in the electrodes.

DMFCs are suitable for producing a small amount of power over a long period of time, and used as mobile batteries, etc.

The major reactions that occur are as follows.

Anode: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$
Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Overall Reaction: $CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O$

1.1.4 Phosphoric acid fuel cell (PAFC)

Phosphoric acid fuel cells (PAFCs) use liquid phosphoric acid as the electrolyte.

The operating temperature of PAFCs is approximately 200°C, and their efficiency is approximately 35-46%.

PAFCs do not require high purity hydrogen because the electrolyte is acidic. Hydrogen-rich gas (approx. 80% H_2, 20% CO_2) produced by reforming liquefied natural gas (LNG), liquefied petroleum gas (LPG), or methanol can be used. Ambient air can be used as the oxidant. A platinum catalyst is required to activate the battery and electrode reactions. When reformed LNG is used, the carbon monoxide concentration in the reformed fuel must be reduced to approx. 1% via the CO shift reaction before the fuel is fed to the cell because the platinum catalyst may degrade due to carbon monoxide in the fuel.

PAFCs are mainly used for cogeneration systems for factories and buildings.

The major reactions that occur are as follows.

Anode: $H_2 \rightarrow 2H^+ + 2e^-$
Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Overall Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

1.1.5 Molten carbonate fuel cell (MCFC)

Molten carbonate fuel cells (MCFCs) are fuel cells that use molten carbonates (lithium carbonate, potassium carbonate, etc.) as the electrolyte. Due to their characteristics, they are suitable for large-scale applications such as power plants. They are also used in the FellowSHIP project (320kW fuel cell using LNG on Viking Lady) and in the MC-WAP project (150kW fuel cell using diesel), etc. [3]

The operating temperature of MCFCs is 600-700°C, and their efficiency is approximately 44-66%. Due to the high operating temperature, the use of exhaust heat is effective. When the heat is used as a heat source to drive a steam turbine or gas turbine, higher efficiencies may be expected.

MCFCs typically use nickel alloy for the anode and nickel oxide for the cathode (with lithium embedded in the structure). Because platinum is not used as a catalyst, they can be manufactured at low costs. Another advantage is that various types of fuel, such as LPG, LNG, and methanol, can be used without an external reformer because internal reforming can be performed within the fuel cell.

The major reactions that occur are as follows.

Internal Reforming of LNG:
Steam Reforming: $CH_4 + H_2O \rightarrow CO + 3H_2$
Water Gas Shift Reaction: $CO + H_2O \rightarrow CO_2 + H_2$
Overall Reaction: $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

Fuel Cell Reactions:
Anode: $2H_2 + 2CO_3^{2-} \rightarrow 2H_2O + 2CO_2 + 4e^-$
Cathode: $O_2 + 2CO_2 + 4e^- \rightarrow 2CO_3^{2-}$
Overall Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

1.1.6 Solid oxide fuel cell (SOFC)

Solid oxide fuel cells (SOFCs) are high-temperature fuel cells. As with PEFCs, SOFCs are used as the residential fuel cells called "ENE-FARM." With a capacity of up to 10MW, they are also used in large-scale onshore generators.

The operating temperature of SOFCs is 500-1000°C, and their efficiency is approximately 44-72%.

As with MCFCs, SOFCs do not require any reformer because internal reforming can be performed. In addition to hydrogen, LPG, LNG, and methanol can be used as fuel. SOFCs use a porous ceramic material (e.g. yttria-stabilized zirconia) as the electrolyte. SOFCs use nickel alloy for the anode as with MCFCs. For the cathode, they typically use lanthanum strontium manganite, which is porous and compatible with the electrolyte. Because platinum is not used as a catalyst, SOFCs can be manufactured at low costs. Furthermore, due to the high operating temperature, the use of exhaust heat is effective. Their disadvantages include a long start-up time and low output per volume because they need to be preheated to the operating temperature.

The major reactions that occur are as follows.

Internal Reforming of LNG:
Steam Reforming: $CH_4 + H_2O \rightarrow CO + 3H_2$
Water Gas Shift Reaction: $CO + H_2O \rightarrow CO_2 + H_2$
Overall Reaction: $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

Fuel Cell Reactions:
Anode: $2H_2 + 2O_2^- \rightarrow 2H_2O + 4e^-$
Cathode: $O_2 + 4e^- \rightarrow 2O^{2-}$
Overall Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

Table 1 Types of major fuel cells and their characteristics [5] [8]

		Alkaline (AFC)	Polymer electrolyte (PEFC)	Direct methanol (DMFC)	Phosphoric acid (PAFC)	Molten carbonate (MCFC)	Solid oxide (SOFC)
Electrolyte	Material	Aqueous alkaline solution	Polymer membrane (ion exchange membrane)	Polymer membrane (ion exchange membrane)	Phosphoric acid	Lithium carbonate Potassium carbonate, etc.	Ceramic (stabilized zirconia, etc.)
	Mobile ion	OH^-	H^+	H^+	H^+	CO_3^{2-}	O^{2-}
Internal reforming		Not allowed	Not allowed	---	Not allowed	Allowed	Allowed
Reaction	Catalyst	Nickel, etc.	Platinum-based	Platinum-ruthenium	Platinum-based	Nickel, etc.	Nickel, etc.
	Anode	$H_2 + 4OH^-$ $\rightarrow 4H_2O + 4e^-$	$2H_2 \rightarrow 4H^+ + 4e^-$	$CH_3OH + H_2O$ $\rightarrow CO_2 + 6H^+ + 6e^-$	$H_2 \rightarrow 2H^+ + 2e^-$	$2H_2 + 2CO_3^{2-}$ $\rightarrow 2H_2O + 2CO_2 + 4e^-$	$2H_2 + 2O^{2-}$ $\rightarrow 2H_2O + 4e^-$
	Cathode	$O_2 + 2H_2O + 4e^-$ $\rightarrow 4OH^-$	$O_2 + 4H^+ + 4e^-$ $\rightarrow 2H_2O$	$O_2 + 4H^+ + 4e^-$ $\rightarrow 2H_2O$	$O_2 + 4H^+ + 4e^-$ $\rightarrow 2H_2O$	$O_2 + 2CO_2 + 4e^-$ $\rightarrow 2CO_3^{2-}$	$O_2 + 4e^- \rightarrow 2O^{2-}$
Operating temperature		20 to 150°C	50 to 100°C	50 to 120° C	Approx. 200°C	600 to 700°C	500 to 1000°C
Efficiency		60 to 70%	30 to 44%	10 to 25%	35 to 46%	44 to 66%	40 to 72%
Major applications		Space development	Mobile terminals, residential power supply, automotive power supply	Mobile batteries	Cogeneration	Large-scale generators	Residential power supply, Large-scale generators
Characteristics		・Starts up at normal temperature ・Pure hydrogen and pure oxygen are required	・Downsizing is easy ・Starts up at normal temperature ・LNG, etc. can be used with a reformer ・Expensive platinum catalyst is required	・Downsizing is easy ・Low efficiency and output	・LNG, etc. can be used with a reformer ・Expensive platinum catalyst is required	・High efficiency ・Wide variety of fuel types can be used ・Poor start-up characteristics	・High efficiency ・Wide variety of fuel types can be used ・Poor start-up characteristics

1.2 Fuel Cell Peripherals, etc.

1.2.1 Fuel fed to the fuel cell and fuel reformer

Fuel fed to the fuel cell varies depending on the electrolyte used and the presence of a fuel reformer.

As a fuel, AFCs use pure hydrogen due to its properties, and DMFCs use methanol. Fuel cells with internal reforming functions (MCFCs and SOFCs) can directly use LPG, LNG, and methanol as fuel. Fuel cells without internal reforming functions (PEFCs and PAFCs) require directly use pure hydrogen, or hydrogen derived from LNG, etc. with a fuel reformer.

Steam reforming, which reacts fuel and steam at high temperature, is generally used to produce hydrogen by reforming LPG, LNG, and methanol. Figure 1 shows an example of a typical reforming subsystem. Fuel is mixed with steam and fed to the reformer. It reacts with steam in the presence of a nickel catalyst to yield hydrogen and carbon monoxide. [9]

Reformer : $C_mH_n + mH_2O \rightarrow (n/2+m)\,H_2 + CO$

This reaction is strongly endothermic. Therefore, in order to maintain the reaction, reaction heat must be supplied by burning part of the fuel or hydrogen in exhaust gas from the anode.

The reformed gas contains approximately 12-20% of carbon monoxide. When the fuel is fed to a PEFC or PAFC using a platinum catalyst, carbon monoxide must be reduced or removed via the CO shift reaction to prevent the catalyst from degrading. The CO shift reaction is expressed as follows. A copper-zinc catalyst is used.

CO shift converter : $CO + H_2O \rightarrow CO_2 + H_2$

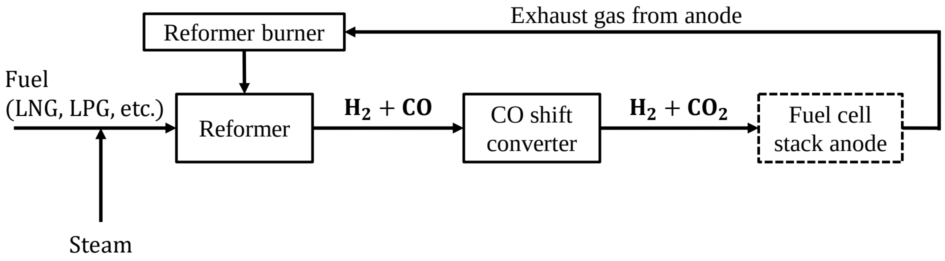


Figure 1 Example of a reforming subsystem

1.2.2 Hydrogen absorbing alloys

Hydrogen absorbing alloys, also known as hydrogen storage alloys, are alloys that absorb hydrogen when cooled down or pressurized, and release it when heated or depressurized. Hydrogen absorbing alloys are considered as one of the hydrogen storage methods for ships. They make it easier to handle hydrogen compared to storing it in high-pressure gas tanks.

When copper is immersed in an acidic solution, it may quickly fracture. This occurs because hydrogen ions in the solution intrude into the copper and embrittle it (hydrogen embrittlement). As a result of research conducted on how to actively store hydrogen in metals using this phenomenon, many types of hydrogen absorbing alloys have been developed.

Hydrogen absorbing alloys can achieve an extremely high hydrogen packing density. They release hydrogen relatively slowly, providing an advantage of preventing accidents due to sudden hydrogen leakage. Their disadvantages include that alloys other than vanadium-base alloys and magnesium alloys are heavy, and rare earth elements and catalyst elements are expensive and scarce. Another problem is that repeated absorption and release of hydrogen may cause hydrogen embrittlement, resulting in a lower absorption rate.

1.3 Example of a Fuel Cell Power Installation

A fuel cell power installation consists of a fuel cell power system, fuel cell control system, safety system, related ancillary systems, and power conversion system, etc.

The fuel cell power system typically consists of fuel cell stacks, pump and purifier that supply process air to the cathode, burner (or oxidizer) for hydrogen exhausted from the anode, and pump that supplies process air to the burner, etc. In a fuel cell that requires fuel reforming, a fuel reformer is also included in the fuel cell power system.

Figure 2 shows an example of a fuel cell power installation. Definitions of terms related to fuel cell power installations are provided in Section 1.1.6, Part B of the Guidelines.

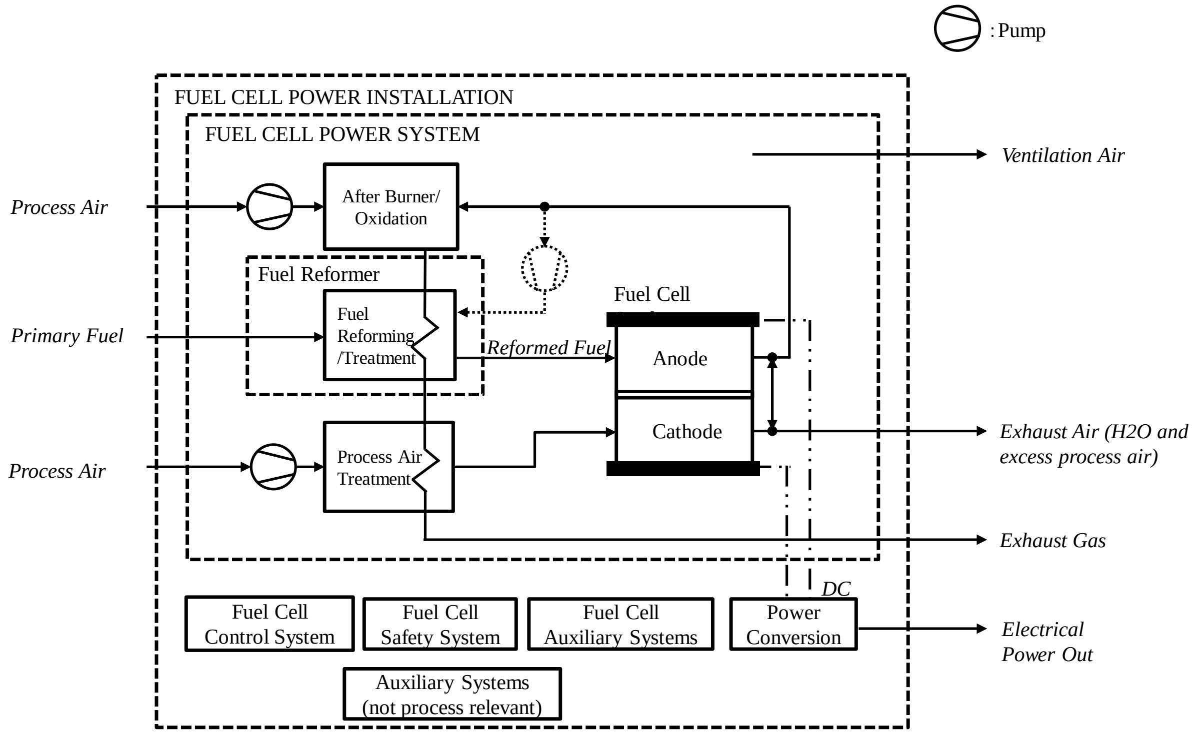


Figure 2 Example of a fuel cell power installation [10]

Chapter 2 SAFETY ISSUES RELATED TO THE USE OF HYDROGEN

This chapter describes the properties of hydrogen that require attention in the safe handling of hydrogen.

2.1 Basic Properties of Hydrogen

Table 2 shows the comparison of physical properties of hydrogen and widely used fuel gases, methane and propane.

Table 2 Comparison of physical properties of hydrogen and other fuel gases [11] [12]

	Hydrogen	Methane	Propane
Specific gravity (Air: 1)	0.0695	0.55	1.52
Diffusion coefficient (in air) @20°C, 1atm	0.61cm^2/s	0.16cm^2/s	0.12cm^2/s
Flammability range (in air)	4 to 76Vol%	5.3 to 14Vol%	2 to 10.5Vol%
Minimum ignition energy	0.02mJ	0.29mJ	0.26mJ
Maximum burning velocity	2.65 m/s	0.4 m/s	0.43 m/s
Combustion heat	10.77MJ/Nm^3	35.9MJ/Nm^3	93.6MJ/Nm^3
Quenching distance	0.6mm	2mm	2mm

As with other fuel gases listed in the table, hydrogen is colorless, odorless, non-toxic, and combustible. Therefore, hydrogen safety mainly relates to combustion and explosion. At the same time, hydrogen has many properties that are completely different from those of conventional fuels, which should be taken into consideration when designing and installing fuel cell power systems.

The following sections describe the specific properties of hydrogen.

2.1.1 Low viscosity

Because of its extremely low molecular weight and viscosity, it is very difficult to completely prevent hydrogen leaks. For example, there have been reported cases of frequent hydrogen leaks from pipe joints with no leak detected in tightness tests with nitrogen. [11] Therefore, helium or a mixture of 5% hydrogen and 95% nitrogen as well as dedicated detectors should be used for tightness tests of hydrogen pipes. [13]

If a leak occurs, hydrogen leaks about 3 times faster than methane and 5 times faster than propane under the same pressure. Therefore, when designing a system using hydrogen, special care should be taken against hydrogen leaks from welds, flanges, seals, and gaskets, etc.

2.1.2 Diffusion and specific gravity

The diffusion rate of hydrogen in air is about 3.8 times that of methane in air. Therefore, with adequate ventilation, it is possible to lower the possibility of an explosive mixture forming near the point of leakage in case of a hydrogen leak.

However, if a leak occurs in a poorly ventilated environment, the concentration may quickly rise to a dangerous level. When hydrogen leaks, it accumulates in upper parts of areas due to the difference in specific gravity between hydrogen and air. The risk of explosion is very high if there is any electrical apparatus or other ignition sources with no measures taken. In order to use hydrogen safely, it is important to work for the prevention of leaks first, and promote quick diffusion and prevent build-up in case of a leak. [14] [15]

2.1.3 Hydrogen embrittlement

Hydrogen embrittlement is a phenomenon in which hydrogen from the surrounding environment diffusing into a metallic material or inherent hydrogen in a material reduces the strength of the material. Hydrogen may embrittle high-strength steels, titanium alloys, and aluminum alloys, causing cracking or fracture at a stress below the yield stress. It is known that low-strength plain carbon steels do not suffer embrittlement damage when in contact with room-temperature, high-pressure hydrogen, and that pure, non-alloyed aluminum has strong resistance to embrittlement.

It has long been known that hydrogen causes embrittlement of metals. However, it is still not fully understood even today. [11]

2.2 Combustion of Hydrogen

2.2.1 Deflagration and detonation

Hydrogen has two types of combustion, deflagration and detonation.

Deflagration is explosive combustion with subsonic flame velocities. It occurs when an unenclosed hydrogen-air mixture is ignited with relatively small energy. In deflagration, the explosion pressure can reach up to 7 to 8 times the initial pressure.

Detonation is combustion in which flames propagate supersonically with shock waves. Detonation poses much greater risks to people and structures than deflagration. It requires a large amount of energy to cause detonation in an unenclosed space. It is known that detonation may occur with a relatively small amount of energy in an enclosed space. In detonation, the explosion pressure can reach up to 20 times the initial pressure. [14] [16]

2.2.2 Flammability range

Explosive reactions do not occur when the concentration of flammable gas is too high or too low. They occur only when it is in a certain range. The lower limit of the concentration range is called the lower explosion limit (LEL), and the higher limit is called the upper explosion limit (UEL).

Hydrogen easily forms an explosive atmosphere when mixed with air. Its explosive limits are 4% (LEL) and 75% (UEL). The flammability range is much wider than other flammable gases (methane: 5-15%, propane: 2-10.5%) (Figure 3). The flammability range that is wider than that of other flammable gases could generally be considered as a disadvantage. However, it should be noted that the lower explosion limit, which has a major effect on risks, is almost equivalent to the others. [17]

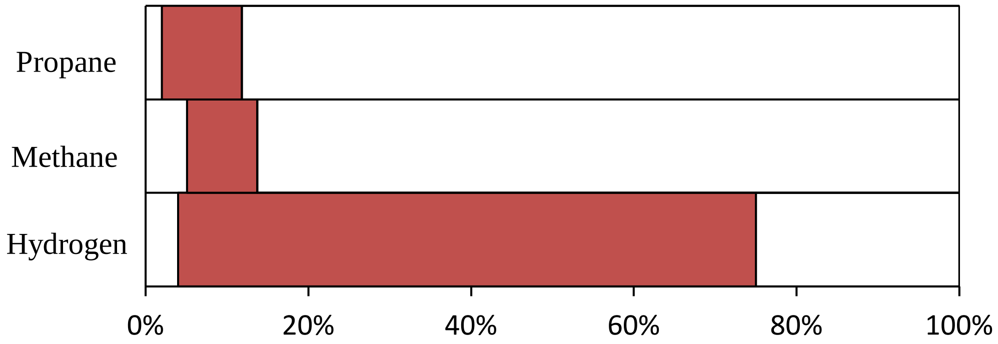


Figure 3 Comparison of flammability ranges

2.2.3 Minimum ignition energy

The minimum ignition energy of hydrogen is 0.02mJ, which is 1/14 of that of methane (0.28mJ) and 1/15 to 1/10 of that of gasoline. Conventional anti-static measures effective for methane may not be effective for hydrogen. The low value of 0.02mJ means hydrogen can be easily ignitable by the slightest static electricity spark caused while getting dressed. It is important to take appropriate anti-static measures. [12] [13]

2.2.4 Burning velocity

The burning velocity of hydrogen at an equivalent ratio of 1 is 2.65m/s, which is significantly greater than that of methane (0.4m/s). When hydrogen is ignited, fire spreads quickly, especially in a closed environment. If pipes are not shut off with valves, fire may spread deep into the pipes. Therefore, appropriate measures should be taken to prevent fire from spreading. [18]

2.2.5 Features of hydrogen fire

Hydrogen burns at high temperature,but gives off less radiant heat than other fuel gases, only about 1/10 of that radiated by an equal-sized propane flame. This means that, while the risk of causing a secondary fire in neighboring objects is low, it is difficult to detect a hydrogen fire based on heat. [13]

The emission wavelength of a hydrogen flame is about 310nm, and it is difficult to visually recognize it directly, as shown in Figure 4 (the wavelengths of visible light are about 360nm to 830nm). An actual fire is not completely invisible because of the flame reactions of metals in the pipes. For early detection, the use of fire detectors is effective. Fire detectors should be selected by taking into account the features of hydrogen fire as described above. [17]

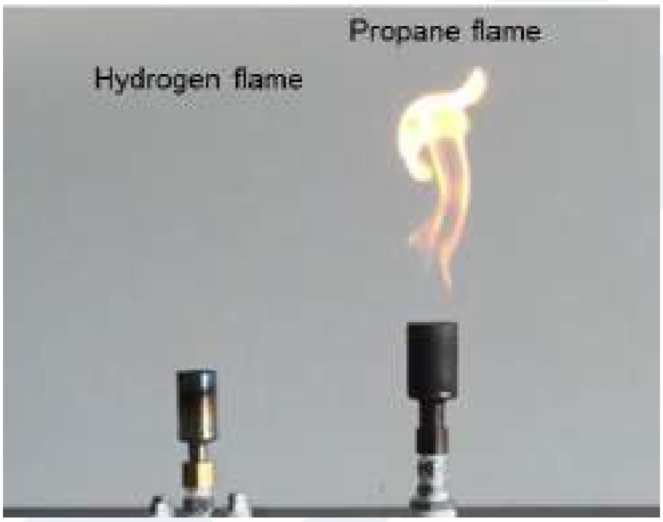


Figure 4 Comparison of a hydrogen flame and propane flame [19]

2.2.6 Quenching distance

Quenching distance is the maximum distance between two parallel plates in which no flame can propagate. Hydrogen has a short quenching distance (0.6mm for hydrogen whereas the maximum safety gap of methane is 2mm). A flame arrester prevents fire from spreading by using small gaps. Therefore, hydrogen requires specially designed flame arresters. Some explosion-proof electrical apparatuses use small gaps to prevent fire from spreading to the outside when a fuel gas is ignited inside. When adopting such an apparatus, one with a proper class should be selected. [12] [18]

Part B DESIGN GUIDELINES FOR SHIPS POWERED BY FUEL CELLS

Part B of the Guidelines describes the design requirements for ships powered by fuel cells that ClassNK considers appropriate based on the MSC.1/Circ.1647 issued in June 2022.

In addition, ClassNK's comments on design requirement items that are considered as requiring further commentary are listed under Note: . It should be kept in mind that any of the items may be modified or deleted based on future discussions.

Chapter 1 INTRODUCTION

The Design Requirements have been developed as an approach for the safety of ships with fuel cell power installations. The Design Requirements are intended to provide the safety that is at least equivalent to that of new and comparable conventional oil-fuelled main and auxiliary machinery installations regardless of the type and fuel of a specific fuel cell. In addition to the Design Requirements, other codes (e.g. IGF Code part A) and provisions (e.g. Part A Guidelines for Ships Using Methyl/Ethyl Alcohol as Fuels in the "Guidelines for Ships Using Alternative Fuels" published by the Society) should be applied depending on the specific fuel cell power system and fuel used. Certain fuel cell power installations use a process of fuel reforming to develop a reformed fuel for use in the fuel cell. The Design Requirements have not been written for the storage of reformed fuels. Additionally, requirements for fuel cell power systems are specified in the Annex of the Guidelines.

1.1 General

1.1.1 Application

Unless expressly provided otherwise, the Design Guidelines apply to ships registered with the Society to which part G of SOLAS chapter II-1 applies, and that have applied for the installation of fuel cell power systems on board, with the appropriate notation of such installation affixed to their class notation.

Note: All passenger ships and cargo ships of over 500 gross tons engaged in international voyages using low flashpoint fuel (a flashpoint below 60°C).

1.1.2 Class notations

For ships that adopt safety measures for fuel cell power installations in accordance with the requirements of these Guidelines, the class notation "Fuel Cell Power Systems" (abbreviated FCS) is to be affixed to their class notation.

1.1.3 Termination of class notations

The Society will delete the relevant class notion if the ship does not appropriately maintain safety measures in accordance with the Guidelines.

1.1.4 Goal

The goal of the Design Guidelines is to provide the safe and reliable delivery of electrical and/or thermal energy through the use of fuel cell technology.

1.1.5 Functional requirements

The Design Guidelines are related to the goals and functional requirements of the IGF Code. In particular, the following apply:

1 The safety, reliability and dependability of the systems should be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery installations, regardless of the specific fuel cell type and fuel.

2 The probability and consequences of fuel-related hazards should be limited to a minimum through arrangement and system design, such as ventilation, detection and safety actions. In the event of gas leakage or failure of the risk reducing measures, necessary safety actions should be initiated.

3 The design philosophy should ensure that risk reducing measures and safety actions for the fuel cell power installation do not lead to an unacceptable loss of power.

4 Hazardous areas should be restricted, as far as practicable, to minimize the potential risks that might affect the safety of the ship, persons on board and equipment.

5 Equipment installed in hazardous areas should be minimized to that required for operational purposes and should be suitably and appropriately certified.

6 Fuel cell spaces should be configured to prevent any unintended accumulation of explosive, flammable or toxic gas concentrations.

7 System components should be protected against external damages.

8 Sources of ignition in hazardous areas should be minimized to reduce the probability of explosions.

9 Piping systems and overpressure relief arrangements that are of suitable design, construction and installation for their intended application should be provided.

10 Machinery, systems and components should be designed, constructed, installed, operated, maintained and protected to ensure safe and reliable operation.

11 Fuel cell spaces should be arranged and located such that a fire or explosion in either will not lead to an unacceptable loss of power or render equipment in other compartments inoperable.

12 Suitable control, alarm, monitoring and shutdown systems should be provided to ensure safe and reliable operation.

13 Fixed leakage detection suitable for all spaces and areas concerned should be arranged.

14 Fire detection, protection and extinction measures appropriate to the hazards concerned should be provided.

15 Commissioning, trials and maintenance of fuel systems and gas utilization machinery should satisfy the goal in terms of safety, availability and reliability.

16 The technical documentation should permit an assessment of the compliance of the system and its components with the applicable rules, guidelines, and design standards used, and principles related to safety, availability, maintainability and reliability.

17 A single failure in a technical system or component should not lead to an unsafe or unreliable situation.

18 Safe access should be provided for operation, inspection and maintenance.

1.1.6 Definitions

The definitions of terms, applicable to Part B of the Guidelines, are given in SOLAS chapter II-2, Part GF of the Rules for the Survey and Construction of Steel Ships as follows:

1 “Exhaust gas” is exhaust from the reformer or anode side of the fuel cell.

2 “Exhaust air” is exhaust from the cathode side of the fuel cell.

3 “Fuel cell” is a source of electrical power in which the chemical energy of a fuel cell fuel is converted directly into electrical and thermal energy by electrochemical oxidation.

4 “Fuel cell power system” is the group of components which may contain fuel or hazardous vapours, fuel cell(s), fuel reformers, if fitted, and associated piping systems.

5 “Fuel cell power installation” is the fuel cell power system and other components and systems required to supply electrical power to the ship. It may also include ancillary systems for the fuel cell operation.

6 “Fuel cell space” is a space or enclosure containing fuel cell power systems or parts of fuel cell power systems.

7 “Fuel cell stack” means the assembly of cells, separators, cooling plates, manifolds and a supporting structure that electrochemically converts, typically, hydrogen-rich gas and air-reactants to DC power, heat and other reaction products.

8 “Fuel reformer” is the arrangement of all related fuel-reforming equipment for processing gaseous or liquid primary fuels to reformed fuel for use in the fuel cells.

9 “LEL” means lower explosive limit, which, in the context of the Design Guidelines, should be taken as identical to the Lower Flammable Limit (LFL) and which is 4.0% vol. fraction for hydrogen.

10 “Reformed fuel” is hydrogen or hydrogen-rich gas generated in the fuel reformer.

11 “Primary fuel” is fuel supplied to the fuel cell power system.

12 “Process air” is air supplied to the reformer and/or the cathode side of the fuel cell.

13 “Ventilation air” is air used to ventilate the fuel cell space.

1.1.7 Alternative design

1 The Design Guidelines contain functional requirements for all appliances and arrangements related to the usage of fuel cell technology.

2 Appliances and arrangements of fuel cell power systems may deviate from those set out in the Design Guidelines, provided such appliances and arrangements meet the intent of the goal and functional requirements concerned and provide an equivalent level of safety of the relevant sections.

3 The equivalence of the alternative design should be demonstrated as specified in SOLAS regulation II-1/55 and approved by the Administration. However, operational methods or procedures should not be applied as an alternative to a particular fitting, material, appliance, apparatus, item of equipment or type thereof which is prescribed by the Design Guidelines.

Chapter 2 DESIGN PRINCIPLES FOR FUEL CELL POWER INSTALLATIONS

2.1 Fuel Cell Spaces

2.1.1 Fuel cell space concept

1 In order to minimize the probability of a gas explosion in a fuel cell space, it should meet the requirements of this section, or an equivalent safety concept.

2 The fuel cell space concept is such that the space is designed to mitigate hazards to non-hazardous levels under normal conditions, but under certain abnormal conditions may have the potential to become hazardous.

3 Equipment protected fuel cell spaces (area classification according to **4.2.2**) is as follows.

(1) Equipment protected fuel cell spaces are considered as hazardous zone 1 and all electrical equipment should be certified for zone 1.

(2) The fuel cell stack itself is not considered a source of ignition if the surface temperature of the stack is kept below 300°C in all operating conditions and the fuel cell power system should be capable of immediately isolating and de-energizing the fuel cell stack under every load and operating condition.

4 In specific cases where the Society considers the prescriptive area classification to be inappropriate, area classification according to IEC 60079-10-1:2020 should be applied according to **4.2.1**, taking into account the following guidance: All electrical equipment needs to comply with the resulting area classification.

5 In specific cases where the Society accepts inerting according to **2.3.3**, the following guidance should be taken into account.

(1) As ignition hazards are mitigated by inerting, there is no need for an immediate (emergency) shutdown of the fuel supply in case of leakage detection.

(2) In case of leakage detection, automatic changeover to the other power supply systems should take place and a controlled shutdown of the fuel cell and the affected fuel supply system should be initiated in order thereby to avoid damage to the fuel cell power system.

2.1.2 The design of fuel cell power systems

The design of fuel cell power systems should comply with industry standards at least equivalent to those acceptable to the IMO.

2.2 Arrangement and Access

1 Fuel cell power installations should be designed for automatic operation and equipped with all the monitoring and control facilities required for safe operation of the system.

2 It should be possible to shut down the fuel cell power system from an easily accessible location outside the fuel cell spaces.

3 Means to safely remove the primary and reformed fuel from the fuel cell power system should be provided.

4 Means should be provided to set a fuel cell power installation into a safe state for maintenance and shutdown.

5 For the auxiliary systems of the fuel cell power system where primary fuel or reformed fuel may leak directly into a system medium (e.g. cooling water), such auxiliary systems should be equipped with appropriate extraction and detection means fitted as close as possible after the media outlet from the system in order to prevent gas dispersion. Gas extracted from the auxiliary system media should be vented to a safe location on the open deck.

6 The reforming equipment, if fitted, may be an integrated part of the fuel cell or arranged as an independent unit with reformed fuel piping connected to the fuel cell(s).

7 Fuel cell space boundaries should be gastight towards other enclosed spaces in the ship.

8 Fuel cell spaces should be arranged outside of accommodation spaces, service spaces, machinery spaces of category A and control stations.

9 Fuel cell spaces should be designed to safely contain fuel leakages and they should be provided with suitable leakage detection systems and should be arranged to avoid the accumulation of hydrogen-rich gas by having simple geometrical shape and no obstructing structures in the upper part.

Note: A thin ceiling that covers the underdeck support structure should not be used as a " no obstructing structures in the upper part."

10 Fuel cell spaces containing fuel reformers should also comply with the requirements relevant for the primary fuel.

11 Where an independent and direct access to the fuel cell spaces from the open deck cannot be arranged, access to fuel cell spaces should be through an air lock.

12 An air lock is not required if following all appropriate technical provisions are made such that access to the fuel cell space is not required.

(1) The equipment inside is to be capable of being safely shut down.

(2) The equipment inside is to be capable of being isolated from the fuel system.

(3) The leakages are to be capable of being drained.

(4) The inside atmosphere is to be capable of being confirmed gas-free.

13 These provisions include but are not limited to:

(1) all controls required for safe operation and gas freeing of the equipment and space should be provided for remote operation from outside the space;

(2) all parameters required for safe operation and gas freeing should be remotely monitored and alarms should be given;

(3) the space openings should be equipped with an interlock preventing operation with the space open;

(4) the spaces should be provided with suitable fuel leakage collection and draining arrangements for remote operation from outside the space;

(5) provisions should be made that the fuel equipment inside can be isolated from the fuel system, drained of fuel and purged safely for maintenance;

2.3 Atmospheric Control of Fuel Cell Spaces

2.3.1 General

Protection of fuel cell spaces by an external boundary that encloses components where fuel is fed can be achieved by ventilation or inerting. These methods should be equally acceptable to ensure the safety of the space.

2.3.2 Ventilation of fuel cell spaces

1 Fuel cell spaces should be equipped with an effective mechanical ventilation system to maintain underpressure of the complete space, taking into consideration the density of potentially leaking fuel gases.

2 For fuel cell spaces on open decks, overpressure ventilation may be considered.

3 The ventilation rate in fuel cell spaces should be sufficient to dilute the average gas/vapour concentration below 25% of the LEL in all maximum probable leakage scenarios owing to technical failures.

4 Any ducting used for the ventilation of fuel cell spaces should not serve any other space.

5 Ventilation ducts from spaces containing reformed fuel piping or release sources should be designed and arranged such that any possibility for gas to accumulate is avoided.

6 Two or more fans should be installed for the ventilation of the fuel cell space providing 100% redundancy upon loss of one fan. 100% ventilation capacity should also be supplied from the emergency source of power.

7 In case of failure of one fan, automatic changeover to another fan should be provided and indicated by an alarm.

8 In case of loss of ventilation or loss of underpressure in the fuel cell space the fuel cell power system should carry out an automatic, controlled shutdown of the fuel cell and isolation of the fuel supply.

9 Ventilation air inlets for fuel cell spaces should be taken from areas which, in the absence of the considered inlet, would be non-hazardous.

10 Ventilation air inlets for non-hazardous enclosed spaces should be taken from non-hazardous areas located at least 1.5m away from the boundaries of any hazardous area.

11 Ventilation air outlets from fuel cell spaces should be located in an open area which, in the absence of the considered outlet, would be of the same or lesser hazard than the ventilated space.

2.3.3 Inerting of fuel cell spaces for fire protection purposes

Inerting should be accepted for atmospheric control of the fuel cell spaces provided that:

(1) protection by inerting is only acceptable where a fuel cell space is not possible to enter during inerting or when inerted, and sealing arrangements should ensure that leakages of inert gas to adjacent spaces are prevented;

(2) the inerting system complies with **chapter 15 of the Fire Safety Systems Code** (FSS Code) and paragraphs **6.13 and 6.14, Part GF of the Rules for the Survey and Construction of Steel Ships**;

(3) the pressure of inerting media should always be kept positive and monitored;

(4) any change in the pressure, indicating a breach of the external outer boundary of fuel cell space, or a breach of the boundary with a space where fuel is flowing (e.g. fuel cell stack, reformer) should activate a controlled shut-off of the fuel supply;

(5) fuel cell space should be equipped with a mechanical ventilation to evacuate the inerting agent, after an inerting release has been initiated;

(6) access to the inerted fuel cell space should only be possible when the space is completely ventilated by fresh air and the fuel supply is interrupted and depressurized or purged; and

(7) the inerting system should not be operable under ongoing maintenance or inspection.

2.4 Materials

1 The materials within the fuel cell power installation should be suitable for the intended application and should comply with recognized standards.

2 The use of combustible materials within the fuel cell power system should be kept to a minimum.

2.5 Piping Arrangement for Fuel Cell Power System

All pipes containing hydrogen or reformed fuel for fuel cell power systems, where fitted, should:

1 not be led through enclosed spaces outside of fuel cell spaces;

2 be fully welded as far as practicable;

3 be arranged to minimize the number of connections; and

4 use fixed hydrogen detectors being capable of detecting a hydrogen leak in places where leakage of hydrogen may occur, such as valves, flanges and seals.

Note: Due to the properties of hydrogen gas, fixed hydrogen detectors should comply with related standards that ClassNK considers appropriate related to required performance such as detection performance, environmental performance, and explosion protection performance (e.g. IEC 60079-29-1, ISO 26142, etc.).

Note: The number of fixed hydrogen detectors to be provided should be determined by taking into consideration the size of the space, equipment arrangement, and ventilation systems, etc. The detectors should be provided for places where accumulation of hydrogen gas may occur and for ventilation outlets.

2.6 Exhaust Gas and Exhaust Air

Exhaust gases and exhaust air from the fuel cell power systems should not be combined with any ventilation except ventilation serving fuel cell spaces and should be led to a safe location in the open air.

Chapter 3 FIRE SAFETY

Note: The requirements in this chapter are additional to those given in SOLAS chapter II-2.

Note: Fuel cell spaces should be equipped with fixed fire detectors. To detect hydrogen fire, smoke detectors alone are not considered adequate for prompt fire detection.

Reference:

The type of fire detectors should be determined based on the fuel used and flammable gases that may exist in the space. Special care should be taken against hydrogen fire because it is difficult to detect due to its properties, i.e. it produces no smoke, gives off less heat, and almost invisible during daylight.

3.1 General Provisions on Fire and Explosion Safety

Fuel cell spaces should be designed to provide a geometrical shape that will minimize the accumulation of gases or formation of gas pockets.

1 The fuel cell space should be regarded as a machinery space of category A according to SOLAS chapter II-2 for fire protection purposes.

2 A fuel cell space should be bounded by "A-60" class divisions. Where this is deemed to be impracticable, the Society may approve alternative boundary designs that provide for an equivalent level of safety.

3 The fire-extinguishing system should be suitable for use with the specific fuel and fuel cell technology. The Society may allow any alternative fire safety measures if the equivalence of the measure is demonstrated by a risk assessment considering the characteristics of fuels for use.

4 A fixed fire detection and fire alarm system complying with the **Chapter 29, Part R of the Rules for the Survey and Construction of Steel Ships** should be provided.

5 The type and arrangement of the fire detection system should be selected with due consideration of the fuels and combustible gases which may be present in fuel cell power installations.

6 Fuel cell spaces should be fitted with suitable (For the selection of suitable fire detectors, ISO/TR 15916:2015 can be taken into account) fire detectors. Smoke detectors alone are not considered sufficient for rapid detection of a fire when gaseous fuels are used.

3.2 Fire and Explosion Protection

1 Fuel cell spaces separated by a single bulkhead should have sufficient strength to withstand the effects of a local gas explosion in either space, without affecting the integrity of the adjacent space and equipment within that space.

2 Failures leading to dangerous overpressure, e.g. gas pipe ruptures or blow out of gaskets, should be mitigated by suitable explosion pressure relief devices and ESD arrangements.

3 The probability of a gas accumulation and explosion in fuel cell spaces should be minimized by a mitigating strategy which may include one or more of the below:

(1) purging the fuel cell power system before initiating the reaction;
(2) purging the system as necessary after shutdown;
(3) providing failure monitoring in the fuel cell fuel containment systems;
(4) monitoring potential contamination of air into fuel cells fuel lines, or fuel cells fuel into air pipes;
(5) monitoring pressures and temperatures;
(6) implementing a pre-programmed sequence to contain or manage the propagation of the reaction to other sections of the fuel cell power system or to the surrounding space; and
(7) any other strategy to the satisfaction of the Society.

3.3 Fire Extinguishing

1 A fixed fire-extinguishing system should be required for fuel cell spaces.

2 The fire-extinguishing system should be suitable for use with the specific primary and reformed fuel and fuel cell technology proposed.

3 Fixed fire-extinguishing systems should be selected having due regard to the fire growth potential of the protected spaces and are to be readily available.

Note: Characteristic of hydrogen fires are not visible and do not produce smoke (This does not apply if the fire has spread to other substances by hydrogen fire). In addition, since the energy required for ignition of hydrogen is low, reignition and explosion may occur due to heat and friction if unburned hydrogen gas remains even once the fire is extinguished. Considering the above characteristics of hydrogen, fire detection and extinguishing methods should be considered. However, in the event of a hydrogen fire, it is first and foremost important to prevent hydrogen leakage.

3.4 Fire Dampers

1 Air inlet and outlet openings should be provided with fail-safe automatic closing fire dampers which should be operable from outside the fuel cell space.

2 Before actuation of the fire-extinguishing system, the fire dampers should be closed.

Chapter 4 ELECTRICAL SYSTEMS

4.1 General Provisions on Electrical Systems

1 Electrical equipment should not be installed in hazardous areas unless essential for operational purposes or safety enhancement.

2 When electrical equipment including components of fuel cell power systems is installed in hazardous areas it should be selected, installed and maintained in accordance with standards at least equivalent to those acceptable to the Society (IEC 60079-10:2020).

3 Means should be provided for protection of the fuel cell installation against short circuits and flow of reverse current.

Note: The table below lists the gas groups and temperature classes of major primary fuels according to IEC 60079.

	Gases and Vapours groups	Temperature Class
Methane (LNG)	IIA	T1
Propane	IIA	T1
Butane	IIA	T2
Propane/butane mixture	IIA	T2
Hydrogen	IIC	T1
Methanol	IIA	T2
Ethanol	IIB	T2

4.2 Area Classification

4.2.1 Area classification

In order to facilitate the selection of appropriate electrical apparatus and the design of suitable electrical installations, hazardous areas are categorized according to 4.2.2, 4.2.3 and 4.2.4. In cases where the prescriptive provisions in 4.2.2, 4.2.3 and 4.2.4 are deemed to be inappropriate, area classification according to IEC 60079-10-1:2020 should be applied with special consideration by the Society.

4.2.2 Hazardous areas zone 0

The following areas should be treated as hazardous area zone 0:

(1) The interiors of buffer tanks, reformers, pipes and equipment containing low-flashpoint fuel or reformed fuel.

(2) Any pipework of pressure-relief or other venting

4.2.3 Hazardous areas zone 1

The following areas should be treated as hazardous area zone 1:

(1) Areas on open deck, or semi-enclosed spaces on deck, within 3 m of any hydrogen or reformed fuel or purge gas outlets or fuel cell space ventilation outlets.
(2) Areas on open deck, or semi-enclosed spaces on deck, within 3 m of fuel cell exhaust air and exhaust gas outlets.
(3) Areas on open deck or semi-enclosed spaces on deck within 1.5 m of fuel cell space entrances, fuel cell space ventilation inlets and other openings into zone 1 spaces.
(4) Areas on open deck or semi-enclosed spaces within 3 m in which other sources of release of hydrogen or reformed fuel are located.
(5) Fuel cell spaces.

4.2.4 Hazardous areas zone 2

The following areas should be treated as hazardous area zone 2:

(1) Areas within 1.5 m surrounding open or semi-enclosed spaces of zone 1 as specified above, if not otherwise specified.
(2) Air locks.

4.2.5 Ventilation ducts

Ventilation ducts should have the same area classification as the ventilated space.

4.3 Risk Analysis

1 For any new or altered concept or configuration of a fuel cell power installation a risk analysis should be conducted in order to ensure that any risks arising from the use of fuel cells affecting the integrity of the ship are addressed. Consideration should be given to the hazards associated with installation, operation and maintenance, following any reasonably foreseeable failure.

2 The risks should be analysed using acceptable and recognized risk analysis techniques and mechanical damage to components, operational and weather-related influences, electrical faults, unwanted chemical reactions, toxicity, auto-ignition of fuels, fire, explosion and short-term power failure (blackout) should as a minimum be considered. The analysis should ensure that risks are eliminated wherever possible. Risks which cannot be eliminated should be mitigated as necessary.

Chapter 5 CONTROL, MONITORING AND SAFETY SYSTEMS

5.1 General Provisions on Control, Monitoring and Safety Systems

1 Safety-related parts of the fuel cell control systems should be designed independent from any other control and monitoring systems or should comply with the process as described in industry standards (ISO 13849-1:2015-06) acceptable to the Society for the performance level or equivalent.

2 The fuel cell should be monitored according to the manufacturer's recommendations.

Note: Typical examples of items to be monitored:

1. cell voltage;
2. cell voltage fluctuation;
3. exhaust gas temperature;
4. fuel cell internal temperature; and
5. current.

Typical examples of recommended additional items to be monitored:

1. process air flow rate;
2. process air pressure;
3. coolant flow rate, pressure, and temperature (if used);
4. fuel flow rate;
5. fuel temperature;
6. fuel pressure;
7. hazardous gases in exhaust gas;
8. process water level, pressure, purity, etc.; and
9. other parameters required to monitor life/degradation.

5.2 Gas or Vapour Detection

1 A permanently installed gas/vapour detection system should be provided for:

(1) fuel cell spaces;

(2) air locks (if any);

(3) expansion tanks/degassing vessels in the auxiliary systems of the fuel cell power system where primary fuel or reformed fuel may leak directly into a system medium (e.g. cooling water); and

(4) other enclosed spaces where primary/reformed fuel may accumulate.

2 The detection systems should continuously monitor for gas/vapour. The number of detectors in the fuel cell space should be considered taking into account the size, layout and ventilation of the space. The detectors should be located where gas/vapour may accumulate and/or in the ventilation outlets. Gas dispersal analysis or a physical smoke test should be used to find the best arrangement.

3 Two independent gas detectors located close to each other are required for redundancy reasons. If the gas detector is of the self-monitoring type, the installation of a single gas detector can be permitted.

5.3 Ventilation Performance

In order to verify the performance of the ventilation system, a detection system of the ventilation flow and of the fuel cell space pressure should be installed. A running signal from the ventilation fan motor is not sufficient to verify performance.

5.4 Bilge Wells

Bilge wells in fuel cell spaces should be provided with level sensors.

5.5 Manual Emergency Shutdown

Manual activation of emergency shutdown should be arranged in the following locations as applicable:

(1) navigation bridge;
(2) onboard safety centre;
(3) engine control room
(4) fire control station; and
(5) adjacent to the exit of the fuel cell space.

5.6 Actions of the Alarm System and Safety System

5.6.1 Gas or vapour detection

1 Gas/vapour detection in a fuel cell space above a gas or vapour concentration of 20% LEL should cause an alarm.

2 Gas/vapour detection in a fuel cell space above a gas or vapour concentration of 40% LEL should shut down the affected fuel cell power system and disconnect ignition sources and should result in automatic closing of all valves required to isolate the leakage. If not certified for operation in zone 1 hazardous areas, the fuel cell stack should be immediately electrically isolated and de-energized. Valves in the primary fuel system supplying liquid or gaseous fuel to the fuel cell space should close automatically.

3 Gas/vapour detection should be provided in the fuel cell's coolant "supply/header" tank, and this should cause an alarm

5.6.2 Liquid detection

Detection of unintended liquid leakages in the fuel cell space should trigger an alarm. A possible means of detection would be a bilge high-level alarm.

5.6.3 Loss of ventilation

1 Loss of ventilation in a fuel cell space should result in an automatic shutdown of the fuel cell by the process control within a limited period of time. The period for the shut down by process control should be considered on a case-by-case basis based on the risk analysis.

2 After the period has expired, a safety shutdown should be carried out.

5.6.4 Emergency shutdown push buttons

Actuation of the emergency shutdown push button should interrupt the fuel supply to the fuel cell space and de-energize the ignition sources inside the fuel cell space.

5.6.5 Loss of fuel cell coolant

Loss of fuel cell coolant should result in an automatic shutdown of the fuel cell by the process control within a limited period of time. To prevent a potential coolant release in the fuel cell space, a secondary containment of the coolant pipe should be provided or the equipment within the fuel cell space should be protected from a coolant release. Consideration should be given to the safe removal of the coolant.

5.6.6 Fire detection

Fire detection within the fuel cell space should initiate automatic shutdown and isolation of the fuel supply.

5.6.7 Fuel cell high-temperature shutdown

For fuel cell spaces rated as hazardous zone 1 where the fuel cell stack is not certified for operation in hazardous zone 1 and the surface temperature of the fuel cell stack exceeds 300°C, the fuel cell power system should immediately shut down and isolate the affected fuel cell space.

5.7 Alarms

1 The alarm provisions in section **5.6**, as well as table 1, specify fuel cell power installation alarms.

2 Alarms additional to the ones required by table 1 may be recommended for unconventional or complex fuel cell power installations.

Table 1 Alarms

	Alarm conditions
Gas detection at 20% LEL	
Fuel cell spaces	HA
Expansion tanks/degassing vessels in systems for heating/cooling	HA
Air locks	HA
Other enclosed spaces where primary/reformed fuel may accumulate	HA
Liquid detetction	
Fuel cell space as per **5.6.2**	HA
Ventilation	
Reduced ventilation in fuel cell spaces	LA
Other alarm conditions	
Air lock, more than one door moved from closed position	A
Air lock, door open at loss of ventilation	A
A = Alarm activated for logical value LA = Alarm for low value HA = Alarm for high value	

5.8 Safety Actions

1 The safety action provisions in **section 5.6** and **Table 2** specify fuel cell power installations safety actions to limit the consequences of system failures.

2 Safety actions additional to those required by **Table 2** may be recommended for unconventional or complex fuel cell power installations.

Table2 Safety actions

	Alarm	Shutdown of fuel cell space valve	Shutdown of ignition source	Signal to other control/safety systems for additional action
Loss of fuel cell coolant as per **5.6.6**	X	X		
40% LEL inside fuel cell space (includes detection of hydrogen leaks as **2.5-1(4)**)	X	X	X	If not certified for operation in zone 1 hazardous areas, the fuel cell stack should be immediately electrically isolated and de-energized
Loss of ventilation or loss of negative pressure in a fuel cell space	X	X		The fuel cell should be automatically shut down by process control
Fire detection within the fuel cell space	X	X	X	Shutdown of ventilation, release of ire-extinguishing system
Emergency shutdown button	X	X	X	
Fuel cell stack Surface temperature >300°C	X	X	X	If fuel cell stack is not certified for zone 1

Annex: FUEL CELL POWER SYSTEMS

Chapter 1 General

1.1 Scope

1 This annex applies to fuel cell power systems using hydrogen as fuel. Other systems are to be specified separately.

2 Fuel cell power systems and their components are to be in accordance with relevant requirements in **Part D, Part GF** and **Part H of the Rules**, in addition to the requirements of this annex.

1.2 Equivalency

Fuel cell power systems and their components not in accordance with the requirements of this annex may be accepted provided that they are deemed to be equivalent by the Society to those approved in accordance with this annex.

1.3 Submission of Plans and Documents

The plans and documents to be submitted are as follows.

(1) Specifications for fuel cell power systems
(2) Safety concept for fuel cell power systems
(3) Documents related to risk analysis
(4) Arrangement of machinery for fuel cell power systems
(5) Piping diagram (including fuel piping, air piping, cooling water piping, etc.)
(6) Specification for piping systems (including piping, valves, flanges, pipe fittings, etc.)
(7) Plans of arrangement of electrical equipment and cable installation
(8) Plans indicating any hazardous areas
(9) Specifications for electrical installations
(10) Lists of electrical equipment (including copies of certificates in the case of certified safety equipment)
(11) Specifications for control systems of fuel cell power systems
(12) Control system diagrams for fuel cell power systems (including monitoring, safety and alarm systems)
(13) Instrumentation lists for control systems (including alarm set points, etc.)
(14) Test program for fuel cell power systems
(15) Instruction manual for fuel cell power systems (including maintenance procedure)

(16) Various calculation sheets
  (a) Strength calculation sheets for fuel pipes
  (b) Strength calculation sheets for pressurized parts of fuel cells
  (c) Calculation sheets for ventilating frequency in fuel cell spaces
(17) Other plans and documents deemed necessary by the Society

1.4 Definitions

For the purpose of this annex, the terms used have the meanings defined in the following paragraphs in addition to **1.1.6 of Part B**.

1 Fuel cell module refers to a basic unit of a fuel cell power system consisting of one or more fuel cell stack(s), piping system for fuels, air and exhausts, electrical connections, and enclosure, etc.

2 Gas refers to hydrogen in a gaseous state.

3 Gas piping refers to piping containing gas or air/gas mixtures, including venting pipes.

4 Crossover refers to leakage between the fuel electrode side and the oxygen electrode side of a fuel cell in either direction, generally through the electrolyte. It generally refers to leakage of fuel toward the oxygen electrode side, which causes a decrease in the voltage of the fuel cell.

1.5 Risk Analysis

For fuel cell power systems, risk analysis is to be carried out in accordance with the following (1) to (4).

(1) Scope of the risk analysis

The risk analysis is to address the following (a) to (d). With regard to the scope of the risk analysis, it is to be noted that failures in systems external to the fuel cell power system, such as fuel storage or fuel gas supply systems, may require action from the control and monitoring system in the event of an alarm or fault condition.

  (a) A failure or malfunction of any system or component involved in the gas operation of the fuel cell power system
  (b) A gas leakage of the fuel cell power system
  (c) The safety of the system in case of emergency shutdown or blackout when operating
  (d) The interactions between the gas fuel system and the fuel cell power system

(2) Form of the risk analysis

The risk analysis is to be carried out in accordance with international standard *ISO 31010:2009* or other recognized standards. The required analysis is to be based on the single failure concept, which means that only one failure needs to be considered at the same time. Both detectable and non-detectable failures are to be considered. Consequential failures, i.e.

failures of any component directly caused by a single failure of another component, are also to be considered.

(3) Procedure for the risk analysis

The risk analysis is to be in accordance with the following procedure. The results of the risk analysis are to be documented.

(a) All reasonably foreseeable hazards, hazardous situations and events throughout the anticipated fuel cell power system’s lifetime have been identified.

(b) The risk for each of these hazards has been estimated from the combination of probability of occurrence of the hazard and of its foreseeable severity.

(c) The two factors which determine each one of the estimated risks (probability and severity) have been eliminated or reduced to a level not exceeding the acceptable risk level, as far as is practically possible, through

i) an inherently safe design of the construction and its methods, or

ii) passive control of energy releases without endangering the surrounding environment or by safety related control functions.

(d) For residual risks which could not have been reduced, labels, warnings or mandatory special training shall be given, considering the need for understanding by the persons which are in the area of the hazards.

(4) Risks and hazards to be analyzed

The risk analysis required for fuel cell power systems is to cover at least the following (a) and (b).

(a) The risk analysis is to also consider the following risks.

i) stack temperature

ii) stack and/or cell voltage

iii) pressure of pressurized parts

iv) flow rates of fuel

(b) The risk analysis is to include, but is not limited to, measures against the following hazards (i) to (viii).

i) mechanical hazards

sharp surfaces, tripping hazards, moving masses and instability, strength of materials, and liquids or gases under pressure

ii) electrical hazards

contact of persons with live parts, short-circuits, or high voltage

iii) EMC hazards

malfunctions of the fuel cell module when exposed to electromagnetic phenomena or malfunctions of other (nearby) equipment due to electromagnetic emissions from the fuel cell module

iv) thermal hazards

hot surfaces, release of high temperature liquids or gases, and thermal fatigue

v) fire and explosion hazards
flammable gases or liquids, potential for explosive mixtures during normal or abnormal operating conditions, potential for explosive mixtures during faulted conditions

vi) malfunction hazards
unsafe operation due to failures of software, control circuit or protective/safety components or incorrect manufacturing or mis-operation

vii) material and substance hazards
material deterioration, corrosion, embrittlement, and toxic releases

viii) environmental hazards
unsafe operation in hot/cold environments, rain, flooding, wind, earthquake, external fire, and smoke

Chapter 2 CONSTRUCTION AND EQUIPMENT OF FUEL CELL POWER SYSTEMS

2.1 General

1 The fuel cell power system is to be designed in accordance with a performed risk analysis.

2 The fuel cell power system and its components are to be suitable for the range of temperatures, pressures, flow rates, voltages and currents to which they are subjected during intended usage.

3 The fuel cell power system is to be resistant to the reactions, processes and other conditions to which they are exposed during intended usage.

4 The quality and thickness of the materials used in the fuel cell power system, their fitting elements and terminals and the method of assembling the various parts, are to be such that the constructional and operational characteristics are not significantly altered during a reasonable lifetime and under normal conditions of installation and use.

5 All parts of the fuel cell power system are to withstand the mechanical, chemical and thermal conditions to which they may be subjected during normal use.

6 The fuel cell power system is to be so designed and constructed that the emission of airborne noise is reduced to a suitable level.

7 The fuel cell power system is not to generate electromagnetic disturbances above the levels appropriate for its intended places of use. In addition, the equipment is to have an adequate level of immunity to electromagnetic disturbances so that it can operate correctly in its intended environment.

8 Measures are to be taken to eliminate any risk of injury caused by contact with, or proximity to, external surfaces of the fuel cell power system enclosure, handle, grips or knobs at high temperatures.

9 The manufacturer is to declare the specifications for gas and cooling water allowable to the fuel cell power system.

10 Components containing or likely to contain gas are to be designed in accordance with the following (1) to (4).

(1) Minimize the risk of fire and explosion so as to demonstrate an appropriate level of safety commensurate with that of an oil-fuelled engine.

(2) Mitigate the consequences of a possible explosion to a level providing a tolerable degree of residual risk, due to the strength of the component(s) or the fitting of suitable pressure relief devices of an approved type.

(3) Refer to **10.2, Part GF of the Rules**

(4) Discharge from pressure relief devices is to prevent the passage of flame to the fuel cell space and be arranged such that the discharge does not endanger personnel or damage other machinery components or systems.

2.2 Construction and Strength

2.2.1 Materials

1 Components and materials inside the classified gas flammable atmospheres are to be constructed so that propagation of fire and ignition is mitigated or are to make use of materials complying with *IEC60695* series.

2 Membranes, or other materials within the fuel cell stack volume which comprise less than 10 % of the total fuel cell module mass, are considered to be of limited quantity and are permissible without flame spread ratings in the preceding **1**.

3 The mechanical characteristics of insulating materials that affect functional behavior, for example compressive strength, shall comply with the design criteria at a temperature up to at least 20 K or 5 % (whichever is higher) above the maximum temperature observed under normal operation, but not less than 80 °C.

4 Special consideration is to be given to materials in parts exposed to hydrogen, such as aging behavior, embrittlement, porosity, etc.

5 Materials are to retain their mechanical stability with respect to strength (fatigue properties, endurance limit, creep strength) when exposed to the full range of service conditions and lifetime.

6 Materials are to be sufficiently resistant to the chemical and physical action of the fluids that the fuel cell power system contain and to environmental degradation.

2.2.2 Pressurized Parts

1 If fuel cell modules include gas-tight and pressurized enclosures, those enclosures are to comply with standards deemed appropriate by the Society.

2.3 Safety Systems

2.3.1 Protection Against Explosions and Leakage

1 Air (oxidant) supply and exhaust gas pipes are to be fitted with suitable pressure relief systems unless designed to withstand the worst-case overpressure due to ignited gas leaks.

2 The pressure relief systems specified in the preceding -1 are not to continuously discharge exhaust gas into enclosed spaces. Venting due to activation of the system is to be led away from locations where personnel may normally be present.

3 Gas fuel injection lines are to be provided with non-return valves or devices which have capabilities equivalent to those of the valves.

4 For fuel cell modules, measures such as ventilation and gas detection are to be taken to prevent leakage into and out of the fuel cell module.

5 Measures are to be taken against crossover in fuel cells, such as monitoring cell voltage.

2.4 Accessory Equipment

2.4.1 Fuel Cell Modules

1 Fuel cell modules are to be designed in accordance with IEC 62282-2-100 or standards deemed appropriate by the Society.

2 Fuel cell modules are to be type tested in accordance with 4.1.

2.4.2 Air Supply Systems (Oxidant Supply Systems)

1 The air supply system on the fuel cell power system is to be designed in accordance with **2.1.10**.

2 In case of a single fuel cell power installation, the installation is to be capable of operating at sufficient load to maintain power to essential consumers after opening of the pressure relief devices in an explosion event. Sufficient power for propulsion capability is to be maintained.

3 Load reduction is to be considered on a case-by-case basis, depending upon the installation configuration (single or multiple) and type of relief mechanism (self-closing valve or bursting disk).

2.4.3 Exhaust Gas Systems

1 The exhaust gas system on the fuel cell power system is to be designed in accordance with **2.1.10**.

2 In case of a single fuel cell power installation, the installation is to be capable of operating at sufficient load to maintain power to essential consumers after opening of the pressure relief devices in an explosion event. Sufficient power for propulsion capability is to be maintained.

3 Continuous relief of exhaust gas (through open rupture disc) into the engine room or other enclosed spaces is not acceptable.

4 The exhaust gas system is to be constructed with material resistant to corrosion by condensate.

5 Means, such as drainage, are to be provided to prevent water, ice or other debris from accumulating inside or obstructing the exhaust pipe.

2.4.4 Gas Fuel Pipes

1 Gas fuel pipes are to be provided with effective protective shielding against gas fuel bursting due to pipe failure, except where deemed appropriate by the Society.

2 Only approved type flexible tubes are to be used as protective shielding.

3 Gas fuel pipes are to be provided with systems for inerting and gas-freeing.

4 Expansion joints provided for gas fuel pipes are to be approved in accordance with the requirements in **Annex 1 “Guidance for Equipment and Fittings of Ships Using Low-flashpoint Fuels”**.

5 For piping attached to fuel cell power systems, the piping is to be designed in accordance with the criteria for gas piping (design pressure, wall thickness, materials, piping fabrication and joining details etc.) as given in Chapter 7, Part GF of the Rules.

6 Non-metallic pipes and pipe fittings are to be approved in accordance with the requirements in **"Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use"**. Also, the following is to be noted.

(1) Protection against the possibility of overheating

(2) When used in hazardous areas, the design is to be electrically conductive or capable of avoiding static charge build-up

2.4.5 Terminals and electrical connections

1 Electrical equipment is to be designed in accordance with **Part H of the Rules** or standards deemed appropriate by the Society.

2 Electrical equipment installed in hazardous areas is to comply with requirements of **4.2.4, Part H of the Rules.**

3 Power connections to external circuitry are to be as follows in (1) to (4).

(1) fixed to their mountings with no possibility of self-loosing,

(2) constructed in such a way that the conductors cannot slip out from their intended location,

(3) such that proper contact is ensured without damage to the conductors that would impair the ability of the conductors to fulfil their function, and

(4) so secured against turning, twisting or permanently deforming during normal tightening onto the conductor.

4 Terminals of the fuel cell power system are to comply with requirements in **Part H of the Rules** or for terminals and electrical connections in the application standards deemed appropriated by the Society.

5 Non-current-carrying exposed metal parts of fuel cell power systems which are not intended to be live, but which are liable under fault conditions to become live are to be effectively earthed.

2.4.6 Enclosure

1 The degree of protection of the fuel cell power system enclosure is to be in accordance with Table H2.1.3-6, Part H of the Guidance, depending on the area of installation.

2 The fuel cell power system enclosure is to be designed to safely contain any anticipated hazardous liquid leaks of liquid fuel. The containment means is to have a capacity of 110 % of the maximum volume of fluid anticipated to leak.

2.4.7 Cooling Water Systems

1 Water used in the fuel cell power systems is to be of the specified quality and supply characteristics.

2.4.8 Condensate Disposal Systems

1 Measures shall be taken to ensure against condensate accumulation.

2 Measures shall be taken to ensure that vent gas does not escape through condensate drain lines.

Chapter 3 CONTROL AND SAFETY SYSTEMS

3.1 General

1 Control systems for the operation of fuel cell power systems are to be in accordance with the requirements of **18.2, Part D of the Rules**.

2 The gas supply valves are to be controlled by the control system or by the gas demand.

3 The fuel cell power system is to be designed in such a way that it withstands all normal operating conditions as defined by the manufacturer's specification without any damage. Abnormal operating conditions are to be covered according to the risk analysis.

4 In the fuel cell power system, the functions to detect the following abnormalities, so far as applicable, are recommended as a standard.

(1) Pressure or temperature of the gas fuel – High
(2) Pressure or temperature of the steam system – High
(3) Cell stack temperature – High
(4) Abnormalities in the operation control system of the fuel cell power system
(5) Cell stack overcurrent
(6) Abnormalities of the generated voltage of the cell stack or the output voltage of the power converter
(7) Supply pressure of inert gas for purging gas fuel – Low
(8) Temperature in enclosure – High
(9) Media failure in operation control of double block bleed valves

5 If an abnormality is detected in the items listed in the preceding **4**, an emergency shutdown is to be performed as follows.

(1) Automatically shut down the output of the fuel cell power system.
(2) Automatically shut down the supply of fuel to the fuel cell power system.
(3) Automatically eliminate combustible gas inside the fuel cell power system.

6 If the risk analysis in 1.5 confirms that the resulting risk is lower than the permissible level, the preceding **4** and **5** may be considered but not mandatory. However, even in this case, the alarms and safety actions required in **Chapter 5 of Part B**, which are related to the fuel cell power system, are to be provided.

Chapter 4 TESTS

4.1 Type Tests of Fuel Cell Modules

1 For each type of fuel cell modules, a type test is to be obtained beforehand.

2 The following type test items are to be included. As far as practicable, the tests are to be carried out in the order described below.

(1) Vibration test
Test methods are to be in accordance with **Table 7.1-1, Chapter 1, Part 7 of the Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use**.

(2) Gas leakage test
Test methods are to be in accordance with *5.3 of IEC 62282-2-100*.

(3) Normal operation test
For the normal operation type test, the fuel cell module is to be operated under the defined normal conditions until thermal equilibrium conditions are achieved. Test methods and measurement values are to be in accordance with *5.4 of IEC 62282-2-100*.

(4) Allowable working pressure test
Test methods are to be in accordance with *5.5 of IEC 62282-2-100*.

(5) Pressure withstanding test of cooling system
Test objects and methods are to be in accordance with *5.6 of IEC 62282-2-100*.

(6) Continuous and short-time electrical rating
Test objects and methods are to be in accordance with *5.7 of IEC 62282-2-100*.

(7) Overpressure test
Test objects and methods are to be in accordance with *5.8 of IEC 62282-2-100*.

(8) Dielectric strength test
Test objects and methods are to be in accordance with *5.9 of IEC 62282-2-100*.

(9) Differential pressure test
Test objects and methods are to be in accordance with *5.10 of IEC 62282-2-100*.

(10) Gas leakage test (repeat)

(11) Normal operation test (repeat)

(12) Flammable concentration test
Test objects and methods are to be in accordance with *5.13 of IEC 62282-2-100*.

(13) Tests of abnormal operating conditions
Tests specified in *5.14 of IEC 62282-2-100* are to be carried out. However, freeze/thaw cycle tests in *5.14.7* need not be carried out. In addition, the following tests are to be carried out in accordance with **Table 7.1-1, Chapter 1, Part 7 of the Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use.**

(a) Cold test

(b) Salt mist test
(c) Inclination test

4.2 Shop Tests of Fuel Cell Modules

Fuel cell modules are to be subjected to the tests and inspections specified in the following (1) and (2) during manufacturing.

(1) Gas-tightness test
For parts and accessories of modules, a gas-tightness test at 1.5 times the nominal operating pressure is to be carried out on all joints and connections of pressure-bearing components.

(2) Dielectric strength withstand test
Dielectric strength tests prescribed in **4.1.2.(8)** are to be carried out with a test duration of 1 second and at ambient temperature.

4.3 Type Tests of Fuel Cell Power Systems

1 For each type of fuel cell power system, a type test is to be obtained beforehand.

2 The following type test items are to be included. As far as practicable, the tests are to be carried out in the order described below.

(1) Leakage tests
Test methods are to be in accordance with *5.4 of IEC 62282-3-100*.

(2) Strength tests
Test methods are to be in accordance with *5.5 of IEC 62282-3-100*.

(3) Normal operation type test
Tests are to be carried out in accordance with the procedure prescribed in *JIS C62282-3-200* (equivalent to *IEC 62282-3-200*).

(4) Electrical overload test
Test methods are to be in accordance with *5.7 of IEC 62282-3-100*.

(5) Alarm and shutdown tests
Alarm and safety action tests are to be carried out in accordance with the risk analysis of **1.5** and **Chapter 3**.

(6) Exhaust gas temperature test
Test methods are to be in accordance with *5.11 of IEC 62282-3-100*.

(7) Surface and component temperatures
Test methods are to be in accordance with *5.12 of IEC 62282-3-100*.

(8) Wind tests
The tests are only applicable for fuel cell power systems intended for outdoor installation and the test methods are to be in accordance with *5.13 of IEC 62282-3-100*.

(9) Rain test

The tests are only applicable for fuel cell power systems intended for outdoor installation and the test methods are to be in accordance with *5.14 of IEC 62282-3-100*.

(10) Blocked condensate line test

A fuel cell power system having a condensate disposal system(s) is, under conditions of a blocked condensate drain line(s), to be tested in accordance with *5.16 of IEC 62282-3-100*. In addition, a condensate discharge test in accordance with *5.17 of IEC 62282-3-100* is to be carried out.

(11) Electrical safety tests

A dielectric strength test (high voltage test) is to be carried out in accordance with *5.18 of IEC 62282-3-100*.

(12) EMC test

An EMC test is to be carried out in accordance with **Table 7.1-1, Chapter 1, Part 7 of the Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use**.

(13) Leakage tests (repeat)

(14) Fuel gas replacement test

The test is to demonstrate that the fuel gas in the enclosure of the fuel cell power system can be reliably replaced with predetermined inert gas or the like.

(15) Salt mist test

A salt mist test is to be carried out in accordance with **Table 7.1-1, Chapter 1, Part 7 of the Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use**.

4.4 Shop Tests of Fuel Cell Power Systems

Fuel cell power systems are to be subjected to the tests and inspections specified in the following (1) to (4) during manufacturing.

(1) Leakage test

The test prescribed in **4.3.2.(1)** is to be carried out.

(2) Dielectric strength test

The test prescribed in **4.3.2.(11)** is to be carried out.

(3) Alarm and shutdown tests

The tests prescribed in **4.3.2.(5)** are to be carried out.

(4) Fuel gas replacement test

The test prescribed in **4.3.2.(14)** is to be carried out.

4.5 Tests after Installation On Board and Sea Trials

The performance tests in accordance with **2.3.1.1.(5), Part B of the Rules** are to be carried out after the fuel cell power system has been installed on board. The test items are to apply mutatis mutandis to **B2.3.1.4, Part B of the Guidance**.

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MSC.1/Circ.1647
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INTERIM GUIDELINES FOR THE SAFETY OF SHIPS USING FUEL CELL POWER INSTALLATIONS

1 The Maritime Safety Committee, at its 105th session (20 to 29 April 2022), having considered a proposal by the Sub-Committee on Carriage of Cargoes and Containers, at its seventh session, recognizing the importance of providing criteria for the arrangement and installation of fuel cell power installations on board ships so as to provide at least the same level of safety and reliability as new and comparable conventional oil-fuelled main and auxiliary machinery installations, approved the *Interim guidelines for the safety of ships using fuel cell power installations*, as set out in the annex.

2 Member States are invited to bring the Interim Guidelines to the attention of shipbuilders, manufacturers, shipowners, ship managers, masters and ship crews, bareboat charterers and all other parties concerned.

3 Member States are invited to recount their experience gained through the use of these Interim Guidelines to the Organization, for the Committee to keep them under review.

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ANNEX

INTERIM GUIDELINES FOR THE SAFETY OF SHIPS USING FUEL CELL POWER INSTALLATIONS

INTRODUCTION

These Interim Guidelines have been developed to provide international standard provisions for ships using fuel cell power installations. The goal of these Interim Guidelines is to provide criteria for the arrangement and installation of fuel cell power installations with at least the same level of safety and reliability as new and comparable conventional oil-fuelled main and auxiliary machinery installations, regardless of the specific fuel cell type and fuel. Depending on the fuel used, other regulations (e.g. IGF Code, part A) and provisions (e.g. *Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel*) are applicable in addition to these Interim Guidelines. Certain fuel cell power installations use a process of fuel reforming to develop a reformed fuel for use in the fuel cell. These Interim Guidelines are not intended to cover the storage of reformed fuels.

1 GENERAL

1.1 Application

Unless expressly provided otherwise these Interim Guidelines apply to ships to which part G of SOLAS chapter II-1 applies.

1.2 Goal

The goal of these Interim Guidelines is to provide safe and reliable delivery of electrical and/or thermal energy through the use of fuel cell technology.

1.3 Functional requirements

These Interim Guidelines are related to the goals and functional requirements of the IGF Code. In particular, the following applies:

.1 The safety, reliability and dependability of the systems should be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery installations, regardless of the specific fuel cell type and fuel.

.2 The probability and consequences of fuel-related hazards should be limited to a minimum through arrangement and system design, such as ventilation, detection and safety actions. In the event of gas leakage or failure of the risk reducing measures, necessary safety actions should be initiated.

.3 The design philosophy should ensure that risk reducing measures and safety actions for the fuel cell power installation do not lead to an unacceptable loss of power.

.4 Hazardous areas should be restricted, as far as practicable, to minimize the potential risks that might affect the safety of the ship, persons on board and equipment.

.5 Equipment installed in hazardous areas should be minimized to that required for operational purposes and should be suitably and appropriately certified.

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.6 Fuel cell spaces should be configured to prevent any unintended accumulation of explosive, flammable or toxic gas concentrations.

.7 System components should be protected against external damages.

.8 Sources of ignition in hazardous areas should be minimized to reduce the probability of explosions.

.9 Piping systems and overpressure relief arrangements that are of suitable design, construction and installation for their intended application should be provided.

.10 Machinery, systems and components should be designed, constructed, installed, operated, maintained and protected to ensure safe and reliable operation.

.11 Fuel cell spaces should be arranged and located such that a fire or explosion in either will not lead to an unacceptable loss of power or render equipment in other compartments inoperable.

.12 Suitable control, alarm, monitoring and shutdown systems should be provided to ensure safe and reliable operation.

.13 Fixed leakage detection suitable for all spaces and areas concerned should be arranged.

.14 Fire detection, protection and extinction measures appropriate to the hazards concerned should be provided.

.15 Commissioning, trials and maintenance of fuel systems and gas utilization machinery should satisfy the goal in terms of safety, availability and reliability.

.16 The technical documentation should permit an assessment of the compliance of the system and its components with the applicable rules, guidelines, design standards used and the principles related to safety, availability, maintainability and reliability.

.17 A single failure in a technical system or component should not lead to an unsafe or unreliable situation.

.18 Safe access should be provided for operation, inspection and maintenance.

1.4 Definitions

For the purpose of these Interim Guidelines, the terms used have the meanings defined in the following paragraphs. Terms not defined have the same meaning as in SOLAS chapter II-2 and the IGF Code.

.1 ***Exhaust gas*** is exhaust from the reformer or anode side of the fuel cell.

.2 ***Exhaust air*** is exhaust from the cathode side of the fuel cell.

.3 ***Fuel cell*** is a source of electrical power in which the chemical energy of a fuel cell fuel is converted directly into electrical and thermal energy by electrochemical oxidation.

.4 ***Fuel cell power system*** is the group of components which may contain fuel or hazardous vapours, fuel cell(s), fuel reformers, if fitted, and associated piping systems.

.5 ***Fuel cell power installation*** is the fuel cell power system and other components and systems required to supply electrical power to the ship. It may also include ancillary systems for the fuel cell operation.

.6 ***Fuel cell space*** is a space or enclosure containing fuel cell power systems or parts of fuel cell power systems.

.7 ***Fuel cell stack*** means the assembly of cells, separators, cooling plates, manifolds and a supporting structure that electrochemically converts, typically, hydrogen-rich gas and air-reactants to DC power, heat and other reaction products.

.8 ***Fuel reformer*** is the arrangement of all related fuel-reforming equipment for processing gaseous or liquid primary fuels to reformed fuel for use in the fuel cells.

.9 ***LEL*** means lower explosive limit, which, in the context of these Interim Guidelines, should be taken as identical to the Lower Flammable Limit (LFL) and which is 4.0% vol. fraction for hydrogen.[1]

.10 ***Reformed fuel*** is hydrogen or hydrogen-rich gas generated in the fuel reformer.

.11 ***Primary fuel*** is fuel supplied to the fuel cell power system.

.12 ***Process air*** is air supplied to the reformer and/or the cathode side of the fuel cell.

.13 ***Ventilation air*** is air used to ventilate the fuel cell space.

1.5 Alternative design

1.5.1 These Interim Guidelines contain functional requirements for all appliances and arrangements related to the usage of fuel cell technology.

1.5.2 Appliances and arrangements of fuel cell power systems may deviate from those set out in these Interim Guidelines, provided such appliances and arrangements meet the intent of the goal and functional requirements concerned and provide an equivalent level of safety of the relevant sections.

1.5.3 The equivalence of the alternative design should be demonstrated as specified in SOLAS regulation II-1/55 and approved by the Administration. However, the Administration should not allow operational methods or procedures to be applied as an alternative to a particular fitting, material, appliance, apparatus, item of equipment or type thereof which is prescribed by these Interim Guidelines.

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[1] For flammability limits for hydrogen refer to ISO /TR 15916:2015 on *Basic considerations for the safety of hydrogen systems*.

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2 DESIGN PRINCIPLES FOR FUEL CELL POWER INSTALLATIONS

2.1 Fuel cell spaces

2.1.1 Fuel cell space concept:

.1 In order to minimize the probability of a gas explosion in a fuel cell space, it should meet the requirements of this section, or an equivalent safety concept.

.2 The fuel cell space concept is such that the space is designed to mitigate hazards to non-hazardous levels under normal conditions, but under certain abnormal conditions may have the potential to become hazardous.

.3 Equipment protected fuel cell spaces - area classification according to 4.2.2: such fuel cell spaces are considered as hazardous zone 1 and all electrical equipment should be certified for zone 1. The fuel cell stack itself is not considered a source of ignition if the surface temperature of the stack is kept below 300°C[2] in all operating conditions and the fuel cell power system should be capable of immediately isolating and de-energizing the fuel cell stack under every load and operating condition (see also table 2).

.4 In specific cases where the Administration considers the prescriptive area classification to be inappropriate, area classification according to IEC 60079-10-1:2020 should be applied according to 4.2.1, taking into account the following guidance: All electrical equipment needs to comply with the resulting area classification.

.5 In specific cases where the Administration accepts inerting according to 2.3.3, the following guidance should be taken into account: As ignition hazards are mitigated by inerting, there is no need for an immediate (emergency) shutdown of the fuel supply in case of leakage detection. In case of leakage detection, automatic changeover to the other power supply systems should take place and a controlled shutdown of the fuel cell and the affected fuel supply system should be initiated in order thereby to avoid damage to the fuel cell power system.

2.1.2 The design of fuel cell power systems should comply with industry standards at least equivalent to those acceptable to the Organization.[3]

2.2 Arrangement and access

2.2.1 Fuel cell power installations should be designed for automatic operation and equipped with all the monitoring and control facilities required for safe operation of the system.

2.2.2 It should be possible to shut down the fuel cell power system from an easily accessible location outside the fuel cell spaces.

2.2.3 Means to safely remove the primary and reformed fuel from the fuel cell power system should be provided.

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[2] The 300°C threshold is taken from ISO/IEC 80079-20-1:2017, where the maximum surface temperature is set to 450°C for Hydrogen and LNG and 300°C for methyl/ethyl alcohol and LPG. To ensure safe operation of fuel cell power systems regardless of the fuel cell and fuel type, these guidelines refer to the lowest threshold for the relevant fuels mentioned in the ISO/IEC 80079-20-1:2017, that is 300°C.

[3] Refer to IEC 62282 series: 62282-2-100:2020 and 62282-3-100:2019.

2.2.4 Means should be provided to set a fuel cell power installation into a safe state for maintenance and shutdown.

2.2.5 For the auxiliary systems of the fuel cell power system where primary fuel or reformed fuel may leak directly into a system medium (e.g. cooling water), such auxiliary systems should be equipped with appropriate extraction and detection means fitted as close as possible after the media outlet from the system in order to prevent gas dispersion. Gas extracted from the auxiliary system media should be vented to a safe location on the open deck.

2.2.6 The reforming equipment, if fitted, may be an integrated part of the fuel cell or arranged as an independent unit with reformed fuel piping connected to the fuel cell(s).

2.2.7 Fuel cell space boundaries should be gastight towards other enclosed spaces in the ship.

2.2.8 Fuel cell spaces should be arranged outside of accommodation spaces, service spaces, machinery spaces of category A and control stations.

2.2.9 Fuel cell spaces should be designed to safely contain fuel leakages and they should be provided with suitable leakage detection systems and should be arranged to avoid the accumulation of hydrogen-rich gas[4] by having simple geometrical shape and no obstructing structures in the upper part.

2.2.10 Fuel cell spaces containing fuel reformers should also comply with the requirements relevant for the primary fuel.

2.2.11 Where an independent and direct access to the fuel cell spaces from the open deck cannot be arranged, access to fuel cell spaces should be through an air lock.

2.2.12 An air lock is not required if appropriate technical provisions are made such that access to the space is not required and not made possible before the equipment inside is safely shut down, isolated from the fuel system, and drained of leakages and the inside atmosphere is confirmed gas-free.

2.2.13 These provisions include but are not limited to:

.1 all controls required for safe operation and gas freeing of the equipment and space should be provided for remote operation from outside the space;

.2 all parameters required for safe operation and gas freeing should be remotely monitored and alarms should be given;

.3 the space openings should be equipped with an interlock preventing operation with the space open;

.4 the spaces should be provided with suitable fuel leakage collection and draining arrangements for remote operation from outside the space; and

.5 provisions should be made that the fuel equipment inside can be isolated from the fuel system, drained of fuel and purged safely for maintenance.

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[4] See also IEC 60079-10-1:2020.

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2.3 Atmospheric control of fuel cell spaces

2.3.1 General

Protection of fuel cell spaces by an external boundary that encloses components where fuel is fed can be achieved by ventilation or inerting. These methods should be equally acceptable to ensure the safety of the space.

2.3.2 Ventilation of fuel cell spaces

2.3.2.1 Fuel cell spaces should be equipped with an effective mechanical ventilation system to maintain underpressure of the complete space, taking into consideration the density of potentially leaking fuel gases.

2.3.2.2 For fuel cell spaces on open decks, overpressure ventilation may be considered.

2.3.2.3 The ventilation rate in fuel cell spaces should be sufficient to dilute the average gas/vapour concentration below 25% of the LEL in all maximum probable leakage scenarios owing to technical failures.

2.3.2.4 Any ducting used for the ventilation of fuel cell spaces should not serve any other space.

2.3.2.5 Ventilation ducts from spaces containing reformed fuel piping or release sources should be designed and arranged such that any possibility for gas to accumulate is avoided.

2.3.2.6 Two or more fans should be installed for the ventilation of the fuel cell space providing 100% redundancy upon loss of one fan. 100% ventilation capacity should also be supplied from the emergency source of power.

2.3.2.7 In case of failure of one fan, automatic changeover to another fan should be provided and indicated by an alarm.

2.3.2.8 In case of loss of ventilation or loss of underpressure in the fuel cell space the fuel cell power system should carry out an automatic, controlled shutdown of the fuel cell and isolation of the fuel supply.

2.3.2.9 Ventilation air inlets for fuel cell spaces should be taken from areas which, in the absence of the considered inlet, would be non-hazardous.

2.3.2.10 Ventilation air inlets for non-hazardous enclosed spaces should be taken from non-hazardous areas located at least 1.5m away from the boundaries of any hazardous area.

2.3.2.11 Ventilation air outlets from fuel cell spaces should be located in an open area which, in the absence of the considered outlet, would be of the same or lesser hazard than the ventilated space.

2.3.3 Inerting of fuel cell spaces for fire protection purposes

2.3.3.1 Inerting should be accepted for atmospheric control of the fuel cell spaces provided that:

.1 protection by inerting is only acceptable where a fuel cell space is not possible to enter during inerting or when inerted, and sealing arrangements should ensure that leakages of inert gas to adjacent spaces are prevented;

.2 the inerting system complies with chapter 15 of the Fire Safety Systems Code (FSS Code) and paragraphs 6.13 and 6.14 of the IGF Code;

.3 the pressure of inerting media should always be kept positive and monitored;

.4 any change in the pressure, indicating a breach of the external outer boundary of fuel cell space, or a breach of the boundary with a space where fuel is flowing (e.g. fuel cell stack, reformer) should activate a controlled shut-off of the fuel supply;

.5 fuel cell space should be equipped with a mechanical ventilation to evacuate the inerting agent, after an inerting release has been initiated;

.6 access to the inerted fuel cell space should only be possible when the space is completely ventilated by fresh air and the fuel supply is interrupted and depressurized or purged; and

.7 the inerting system should not be operable under ongoing maintenance or inspection.

2.4 Materials

2.4.1 The materials within the fuel cell power installation should be suitable for the intended application and should comply with recognized standards.

2.4.2 The use of combustible materials within the fuel cell power system should be kept to a minimum.

2.5 Piping arrangement for fuel cell power system

All pipes containing hydrogen or reformed fuel for fuel cell power systems, where fitted, should:

.1 not be led through enclosed spaces outside of fuel cell spaces;

.2 be fully welded as far as practicable;

.3 be arranged to minimize the number of connections; and

.4 use fixed hydrogen detectors being capable of detecting a hydrogen leak in places where leakage of hydrogen may occur, such as valves, flanges and seals.

2.6 Exhaust gas and exhaust air

Exhaust gases and exhaust air from the fuel cell power systems should not be combined with any ventilation except ventilation serving fuel cell spaces and should be led to a safe location in the open air.

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3 FIRE SAFETY

3.1 General provisions on fire and explosion safety

Fuel cell spaces should be designed to provide a geometrical shape that will minimize the accumulation of gases or formation of gas pockets.

.1 The fuel cell space should be regarded as a machinery space of category A according to SOLAS chapter II-2 for fire protection purposes.

.2 A fuel cell space should be bounded by "A-60" class divisions. Where this is deemed to be impracticable, an Administration may approve alternative boundary designs that provide for an equivalent level of safety.

.3 The fire-extinguishing system should be suitable for use with the specific fuel and fuel cell technology. Administrations may allow any alternative fire safety measures if the equivalence of the measure is demonstrated by a risk assessment considering the characteristics of fuels for use.

.4 A fixed fire detection and fire alarm system complying with the FSS Code should be provided.

.5 The type and arrangement of the fire detection system should be selected with due consideration of the fuels and combustible gases which may be present in fuel cell power installations.

.6 Fuel cell spaces should be fitted with suitable[5] fire detectors. Smoke detectors alone are not considered sufficient for rapid detection of a fire when gaseous fuels are used.

3.2 Fire and explosion protection

3.2.1 Fuel cell spaces separated by a single bulkhead should have sufficient strength to withstand the effects of a local gas explosion in either space, without affecting the integrity of the adjacent space and equipment within that space.

3.2.2 Failures leading to dangerous overpressure, e.g. gas pipe ruptures or blow out of gaskets, should be mitigated by suitable explosion pressure relief devices and ESD arrangements.

3.2.3 The probability of a gas accumulation and explosion in fuel cell spaces should be minimized by a mitigating strategy which may include one or more of the below:

.1 purging the fuel cell power system before initiating the reaction;

.2 purging the system as necessary after shutdown;

.3 providing failure monitoring in the fuel cell fuel containment systems;

.4 monitoring potential contamination of air into fuel cells fuel lines, or fuel cells fuel into air pipes;

.5 monitoring pressures and temperatures;

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[5] For the selection of suitable fire detectors, ISO/TR 15916:2015 can be taken into account.

.6 implementing a pre-programmed sequence to contain or manage the propagation of the reaction to other sections of the fuel cell system or to the surrounding space; and

.7 any other strategy to the satisfaction of the Administration.

3.3 Fire extinguishing

3.3.1 A fixed fire-extinguishing system should be required for fuel cell spaces.

3.3.2 The fire-extinguishing system should be suitable for use with the specific primary and reformed fuel and fuel cell technology proposed.

3.3.3 Fixed fire-extinguishing systems should be selected having due regard to the fire growth potential of the protected spaces and are to be readily available.

3.4 Fire dampers

3.4.1 Air inlet and outlet openings should be provided with fail-safe automatic closing fire dampers which should be operable from outside the fuel cell space.

3.4.2 Before actuation of the fire-extinguishing system, the fire dampers should be closed.

4 ELECTRICAL SYSTEMS

4.1 General provisions on electrical systems

4.1.1 Electrical equipment should not be installed in hazardous areas unless essential for operational purposes or safety enhancement.

4.1.2 Where electrical equipment including components of fuel cell systems is installed in hazardous areas it should be selected, installed and maintained in accordance with standards at least equivalent to those acceptable to the Organization.[6]

4.1.3 Means should be provided for protection of the fuel cell installation against short circuits and flow of reverse current.

4.2 Area classification

4.2.1 In order to facilitate the selection of appropriate electrical apparatus and the design of suitable electrical installations, hazardous areas are divided into zones 0, 1 and 2, according to 4.2.2, 4.2.3 and 4.2.4. In cases where the prescriptive provisions in 4.2.2, 4.2.3 and 4.2.4 are deemed to be inappropriate, area classification according to IEC 60079-10-1:2020 should be applied with special consideration by the Administration.

4.2.2 Hazardous areas zone 0

The following areas should be treated as hazardous area zone 0: the interiors of buffer tanks, reformers, pipes and equipment containing low-flashpoint fuel or reformed fuel, any pipework of pressure relief or other venting.

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[6] Refer to standards IEC 60079-10-1:2020 *Explosive atmospheres Part 10-1: Classification of areas – Explosive gas atmospheres* and guidance and informative examples given in IEC 60092-502:1999, *Electrical Installations in Ships – Tankers – Special features for tankers*.

4.2.3 Hazardous areas zone 1

The following areas should be treated as hazardous area zone 1:

.1 Areas on open deck, or semi-enclosed spaces on deck, within 3 m of any hydrogen or reformed fuel or purge gas outlets or fuel cell space ventilation outlets.

.2 Areas on open deck, or semi-enclosed spaces on deck, within 3 m of fuel cell exhaust air and exhaust gas outlets.

.3 Areas on open deck or semi-enclosed spaces on deck within 1.5 m of fuel cell space entrances, fuel cell space ventilation inlets and other openings into zone 1 spaces.

.4 Areas on open deck or semi-enclosed spaces within 3 m in which other sources of release of hydrogen or reformed fuel are located.

.5 Fuel cell spaces.

4.2.4 Hazardous areas zone 2

The following areas should be treated as hazardous area zone 2:

.1 Areas within 1.5 m surrounding open or semi-enclosed spaces of zone 1 as specified above, if not otherwise specified.

.2 Air locks.

4.2.5 **Ventilation ducts** should have the same area classification as the ventilated space.

4.3 Risk analysis

4.3.1 For any new or altered concept or configuration of a fuel cell power installation a risk analysis should be conducted in order to ensure that any risks arising from the use of fuel cells affecting the integrity of the ship are addressed. Consideration should be given to the hazards associated with installation, operation and maintenance, following any reasonably foreseeable failure.

4.3.2 The risks should be analysed using acceptable and recognized risk analysis techniques and mechanical damage to components, operational and weather-related influences, electrical faults, unwanted chemical reactions, toxicity, auto-ignition of fuels, fire, explosion and short-term power failure (blackout) should as a minimum be considered. The analysis should ensure that risks are eliminated wherever possible. Risks which cannot be eliminated should be mitigated as necessary.

5 CONTROL, MONITORING AND SAFETY SYSTEMS

5.1 General provisions on control, monitoring and safety systems

5.1.1 Safety-related parts of the fuel cell control systems should be designed independent from any other control and monitoring systems or should comply with the process as described in industry standards acceptable to the Organization[7] for the performance level or equivalent.

5.1.2 The fuel cell should be monitored according to the manufacturer's recommendations.

5.2 Gas or vapour detection

5.2.1 A permanently installed gas/vapour detection system should be provided for:

- .1 fuel cell spaces;
- .2 air locks (if any);
- .3 expansion tanks/degassing vessels in the auxiliary systems of the fuel cell power system where primary fuel or reformed fuel may leak directly into a system medium (e.g. cooling water); and
- .4 other enclosed spaces where primary/reformed fuel may accumulate.

5.2.2 The detection systems should continuously monitor for gas/vapour. The number of detectors in the fuel cell space should be considered taking into account the size, layout and ventilation of the space. The detectors should be located where gas/vapour may accumulate and/or in the ventilation outlets. Gas dispersal analysis or a physical smoke test should be used to find the best arrangement.

5.2.3 Two independent gas detectors located close to each other are required for redundancy reasons. If the gas detector is of the self-monitoring type, the installation of a single gas detector can be permitted.

5.3 Ventilation performance

In order to verify the performance of the ventilation system, a detection system of the ventilation flow and of the fuel cell space pressure should be installed. A running signal from the ventilation fan motor is not sufficient to verify performance.

5.4 Bilge wells

Bilge wells in fuel cell spaces should be provided with level sensors.

5.5 Manual emergency shutdown

5.5.1 Manual activation of emergency shutdown should be arranged in the following locations as applicable:

- .1 navigation bridge;
- .2 onboard safety centre;

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[7] Refer to ISO 13849-1:2015-06.

.3 engine control room

.4 fire control station; and

.5 adjacent to the exit of the fuel cell space.

5.6 Actions of the alarm system and safety system

5.6.1 Gas or vapour detection

5.6.1.1 Gas/vapour detection in a fuel cell space above a gas or vapour concentration of 20% LEL should cause an alarm.

5.6.1.2 Gas/vapour detection in a fuel cell space above a gas or vapour concentration of 40% LEL should shut down the affected fuel cell power system and disconnect ignition sources and should result in automatic closing of all valves required to isolate the leakage. If not certified for operation in zone 1 hazardous areas, the fuel cell stack should be immediately electrically isolated and de-energized. Valves in the primary fuel system supplying liquid or gaseous fuel to the fuel cell space should close automatically.

5.6.1.3 Gas/vapour detection should be provided in the fuel cell's coolant "supply/header" tank, and this should cause an alarm.

5.6.2 Liquid detection

Detection of unintended liquid leakages in the fuel cell space should trigger an alarm. A possible means of detection would be a bilge high-level alarm.

5.6.3 Loss of ventilation

5.6.3.1 Loss of ventilation in a fuel cell space should result in an automatic shutdown of the fuel cell by the process control within a limited period of time. The period for the shut down by process control should be considered on a case-by-case basis based on the risk analysis.

5.6.3.2 After the period has expired, a safety shutdown should be carried out.

5.6.4 Emergency shutdown push buttons

Actuation of the emergency shutdown push button should interrupt the fuel supply to the fuel cell space and de-energize the ignition sources inside the fuel cell space.

5.6.5 Loss of fuel cell coolant

Loss of fuel cell coolant should result in an automatic shutdown of the fuel cell by the process control within a limited period of time. To prevent a potential coolant release in the fuel cell space, a secondary containment of the coolant pipe should be provided or the equipment within the fuel cell space should be protected from a coolant release. Consideration should be given to the safe removal of the coolant.

5.6.6 Fire detection

Fire detection within the fuel cell space should initiate automatic shutdown and isolation of the fuel supply.

5.6.7 Fuel cell high-temperature shutdown

For fuel cell spaces rated as hazardous zone 1 where the fuel cell stack is not certified for operation in hazardous zone 1 and the surface temperature of the fuel cell stack exceeds 300°C, the fuel cell power system should immediately shut down and isolate the affected fuel cell space.

5.7 Alarms

5.7.1 The alarm provisions in section 5.6, as well as table 1, specify fuel cell power installation alarms.

5.7.2 Alarms additional to the ones required by table 1 may be recommended for unconventional or complex fuel cell power installations.

Table 1: Alarms

	Alarm conditions
Gas detection at 20% LEL	
Fuel cell spaces	HA
Expansion tanks/degassing vessels in systems for heating/cooling	HA
Air locks	HA
Other enclosed spaces where primary/reformed fuel may accumulate	HA
Liquid detetction	
Fuel cell space as per 5.6.2.1	HA
Ventilation	
Reduced ventilation in fuel cell spaces	LA
Other alarm conditions	
Air lock, more than one door moved from closed position	A
Air lock, door open at loss of ventilation	A
A = Alarm activated for logical value *LA = Alarm for low value* *HA = Alarm for high value*	

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5.8 Safety actions

5.8.1 The safety action provisions in section 5.6 and table 2 specify fuel cell power installations safety actions to limit the consequences of system failures.

5.8.2 Safety actions additional to those required by table 2 may be recommended for unconventional or complex fuel cell power installations.

Table 2: Safety actions

	Alarm	Shutdown of fuel cell space valve	Shutdown of ignition source	Signal to other control/safety systems for additional action
Loss of fuel cell coolant as per 5.6.6.1	X	X		
40% LEL inside fuel cell space (includes detection of hydrogen leaks as per 2.5.1.4)	X	X	X	If not certified for operation in zone 1 hazardous areas, the fuel cell stack should be immediately electrically isolated and de-energized
Loss of ventilation or loss of negative pressure in a fuel cell space	X	X		The fuel cell should be automatically shut down by process control
Fire detection within the fuel cell space	X	X	X	Shutdown of ventilation, release of fire-extinguishing system
Emergency shutdown button	X	X	X	
Fuel cell stack surface temperature >300°C	X	X	X	If fuel cell stack is not certified for zone 1

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