a

INFORMATIVE PUBLICATION 37/I

GUIDELINES FOR THE SAFETY OF SHIPS USING FUEL CELL POWER INSTALLATIONS

May
2022

Publications I (Informative) are issued by Polski Rejestr Statków S.A.
as guidance or explanatory notes to PRS Rules.

GDAŃSK

Informative Publication 37/I – Guidelines for the safety of ships using fuel cell power installations – May 2022 was accepted by the Director for Ship Division and enters into force on 23 May 2022.

© Copyright by Polish Register of Shipping[*], 2022

---

[*] *Polish Register of Shipping means Polski Rejestr Statków S.A., seated in Gdańsk, al. gen. Józefa Hallera 126, 80-416 Gdańsk, Poland,* registered in the Register of Entrepreneurs of the National Court Register, under entry number 0000019880. Polish Register of Shipping, its affiliates and subsidiaries, their respective officers, employees or agents are, individually and collectively, referred to as Polish Register of Shipping or as PRS for short.

PRS/RP, 05/2021

CONTENTS

1 GENERAL INFORMATION

1.1 Introduction

Fuel cells are classified primarily by the kind of electrolyte they employ. This classification determines the kind of electro-chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. At present there exist several types of fuel cells, each with its own advantages, limitations, and potential applications.

Kind of cell	Range of operational temperatures [°C]	Fuel	Electrolyte
PEMFC	40-90	Hydrogen (H_2)	Proton-exchange membrane
AFC	40-200	Hydrogen (H_2)	Potassium hydroxide (KOH)
DMFC	60-130	Methanol (CH_3OH)	Proton-exchange membrane
PAFC	200	Hydrogen (H_2)	Phosphoric acid (H_3PO_4)
MCFC	650	Methane (CH_4), Hydrogen (H_2)	Molten carbonate
SOFC	600-950	Methane (CH_4), Hydrogen (H_2)	Solid oxide

PEMFC – polymer electrolyte membrane fuel cells also called proton exchange membrane fuel cells. They deliver high power density and have relatively low weight and volume compared with other fuel cells. These cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum alloy catalyst. They need only hydrogen, oxygen from the air, and water to operate. They are typically fueled with pure hydrogen supplied from storage tanks or reformers.

PEMFC operate at relatively low temperatures, around 80°C which allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to carbon monoxide (CO) “poisoning”, making it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from a hydrocarbon fuel. This reactor also adds cost.

PEMFC are considered to be the most versatile type of fuel cells currently in production. They produce the most power for a given weight or volume of fuel cell. Because they are lightweight, have such high power-density, and cold-start capability, they qualify for many applications, such as stationary combined-heat-power, land and water transport, portable power and spacecraft applications.

AFC – alkaline fuel cells. They were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water on-board spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of base metals as a catalyst at the anode and cathode. In recent years, novel AFCs that use a polymer membrane as the electrolyte have been developed (**AMFC** cells). These fuel cells are closely related to conventional PEMFC, except that they use an alkaline membrane instead of an acid membrane. The high performance of AFCs is due to the rate at which electro-chemical reactions take place in the cell. They have also demonstrated efficiencies above 60% in space applications.

A key challenge for this fuel cell type is that it is susceptible to “poisoning” by carbon dioxide (CO_2). Even a small amount of CO_2 in the air can dramatically affect cell performance and durability due to carbonate formation. Alkaline cells with liquid electrolytes can be run in a recirculating mode, which allows for electrolyte regeneration to help reduce the effects of carbonate formation in the electrolyte, but the recirculating mode creates problems with shunt currents. The liquid electrolyte systems also suffer from additional concerns including wettability, increased corrosion, and difficulties in handling differential pressures. Alkaline membrane fuel cells (AMFCs) address these concerns and have lower susceptibility to CO_2 “poisoning” than liquid-electrolyte AFCs do. However, CO_2 still affects performance, and performance and durability of the AMFCs still lag that of PEMFCs. AMFCs are being considered for applications in the W to kW scale. Challenges for AMFCs include tolerance to CO_2, membrane conductivity and durability, higher temperature operation, water management, power density, and anode electrocatalysis.

DMFC – direct methanol fuel cells. Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels. DMFCs are powered by pure methanol, which is usually mixed with water and fed directly to the fuel cell anode. These cells do not have many of the fuel storage problems typical of some fuel cell systems because methanol has a higher energy density than hydrogen, though less than gasoline or diesel fuel. Methanol is also easier to transport and supply to the public using current infrastructure because it is a liquid, like gasoline. DMFCs are often used to provide power for portable fuel cell applications such as cell phones or laptop computers.

PAFC – phosphoric acid fuel cells. They make use of liquid phosphoric acid as an electrolyte and porous carbon electrodes containing a platinum catalyst. The acid is contained in a Teflon-bonded silicon carbide matrix. The PAFC is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

PAFCs supplied with hydrogen from fossil fuels are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than PEM cells, which are easily "poisoned" by carbon monoxide. PAFCs are more than 85% efficient when used for the co-generation of electricity and heat but they are less efficient at generating electricity alone (37%–42%). PAFC efficiency is only slightly more than that of combustion-based power plants, which typically operate at around 33% efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. They require much higher loadings of expensive platinum catalyst than other types of fuel cells do, which raises the cost.

MCFC – molten carbonate fuel cells. They are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide matrix. Because they operate at high temperatures of (650°C), base metals can be used as catalysts at the anode and cathode, reducing costs.

Improved efficiency is another reason MCFCs offer significant cost reductions over PAFCs. MCFCs, when coupled with a turbine, can reach efficiencies approaching 65%, considerably higher than the 37%–42% efficiencies of a PAFC plant. When the waste heat is captured and used, overall fuel efficiencies can be over 85%. Unlike AFC, PAFC and PEMFC, MCFCs do not require an external reformer to convert fuels such as natural gas and biogas to hydrogen. At the high temperatures at which MCFCs operate, methane and other light hydrocarbons in these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which reduces cost.

The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Currently it amounts to 40,000 hours (5 years) without decreasing performance and scientists are working on doubling the lifetime by the use of other corrosion-resistant materials as well as by the change of fuel cell designs.

SOFC – solid oxide fuel cells. They make use of a hard, non-porous ceramic compound as the electrolyte. SOFCs are around 60% efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall efficiency can reach 85%. SOFCs operate at very high temperatures up to 950°C . High-temperature operation removes the need for a noble metal catalyst, thereby reducing cost and allows internal reforming, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system.

SOFCs are also the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types can. In addition, they are not "poisoned" by carbon monoxide, which can even be used as fuel. This property allows SOFCs to use natural gas, biogas, and gases made from coal. High-temperature operation has disadvantages – slow startup and significant thermal shielding to retain heat and protect personnel. This basically precludes the use of these cells in transport. The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology.

Ongoing research concerns the possibility of developing lower-temperature SOFCs operating at or below 700°C that have fewer durability problems and cost less. Lower-temperature SOFCs have not yet matched the performance of the higher temperature systems, and materials for their construction are still under development.

1.2 Application

1.2.1 This *Publication* applies to fuel cell power installations used in ships and floating objects classed by PRS. If such installations are to be a part of the main or emergency source of electric power, the guidelines and recommendations contained in this *Publication* should be considered as mandatory requirements.

1.2.2 This *Publication* has been developed on the basis of the *Interim Guidelines for the Safety of Ships Using Fuel Cell Power Installations*, prepared by the IMO CCC (approved as MSC.1/Circ. 1647 on 15 June 2022) Subcommittee Working Group and other sources referred to at the end of the *Publication*. Basic standards related to fuel cells are also specified at the end of the *Publication*.

1.2.3 Principles for materials and fittings, storage, preparation and distribution of low flashpoint liquid and gas fuels, should comply with *IGF Code* and with applicable standards.

1.3 Goal

1.3.1 The goal of this *Publication* is to provide recommendations for safe and reliable delivery of electrical and/or thermal energy through the use of fuel cell technology. Its goal is also to provide recommended criteria for the arrangement and installation of fuel cell power installations, irrespective of the type of applied fuel cells and fuel kind.

1.4 Functional recommendations

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

1.4.2 The probability and consequences of fuel-related hazards should be limited to a minimum through arrangement and design of systems, 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.

1.4.3 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.

1.4.4 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.

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

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

1.4.7 System components should be protected against external damages.

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

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

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

1.4.11 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.

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

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

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

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

1.4.16 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.

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

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

1.5 Definitions

For the purpose of this *Publication* definitions given in this section apply. Undefined terms have the same meaning as given in chapter II-2 of the *SOLAS Convention* and the *IGF Code*.

1.5.1 ***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.

1.5.2 ***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.

1.5.3 ***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.

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

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

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

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

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

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

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

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

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

1.5.13 ***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*.

---

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

1.5.14 ***Unacceptable loss of power*** is when it is not possible to sustain or restore normal operation of the propulsion machinery in the event of one of the essential auxiliaries becoming inoperative, in accordance with *SOLAS Convention*, regulation II-1/26.3.

1.6 Design documentation

Design documentation should comprise the following items:

1.6.1 General documentation of fuel cell power installation, containing:

- General and functional description of the installation;
- Description of safety actions of the installation;
- Arrangement plan of the installation equipment on the ship;
- Hazardous areas and zones plan
- Risk analysis.

1.6.2 Fuel cell space drawings, containing:

- Arrangement plan of fuel cells/stacks;
- Ventilation system and, where installed, space inerting system;
- Electrical installations in the compartment;
- Passive (structural) and active (extinguishing system) fire protection.

1.6.3 Primary/reformed fuel system drawings, containing:

- Fuel bunkering and storage system;
- Fuel reforming system;
- System of fuel supply to cells;
- Systems of pressure release and purge outlets of gas fuel piping;
- Fuel tanks vents;
- Calculations of pipeline diameters;
- Selection of equipment and fittings;
- List of pressure components;
- List of installation materials and components;
- List of certificates and compliance documents.

1.6.4 Documentation of control, monitoring and safety systems and auxiliary systems, containing:

- Fuel cell operation control and monitoring system;
- Description of alarm conditions;
- Safety actions system;
- Fuel cells emergency shutdown system (ESD);
- Gas detection and alarm system;
- Fire detection and alarm systems;
- System of discharge of reaction products from fuel cells;
- Fuel cell cooling system.

1.6.5 Documentation of electrical system of fuel cell power installations.

1.6.6 Final acceptance and tests programme of fuel cell power installation.

1.7 Certificates and documents of compliance

Fuel cell installation equipment and components should be delivered with adequate certificates and/or documents of compliance. PRS decides each time on the kind of required certificate/ document of compliance.

1.8 Operational documentation

Documentation for the safe operation and maintenance of fuel cell power installation should be available on board, including:

.1 design documentation of fuel cell power installations mentioned in para 1.6;
.2 user manual of all systems and devices of fuel cell power installations mentioned in para 1.9;
.3 maintenance plan mentioned in para 1.10.

1.9 User manual

1.9.1 User manual of fuel cell power installations, mentioned in para 1.8.2 should contain at least:

.1 general information on ship operation, including fuel bunkering procedures and, where applicable, unloading, sampling, inerting and gas freeing procedures;
.2 specific properties of primary and reformed fuels used in the fuel cell power installation and special equipment necessary for safe handling of the fuel in question;
.3 emergency procedures to be taken in the event of leakage, fire or poisoning;
.4 how to operate fixed and portable equipment for detecting dangerous gas concentration;
.5 how to operate emergency shutdown systems (ESD), if fitted; and
.6 diagram of the primary and reformed fuel systems.

1.9.2 Diagram of the primary and reformed fuel systems should be permanently displayed in the fuel cell space.

1.10 Maintenance plan

The maintenance plan should include the schedule and information for periodic inspection, testing and maintenance for all systems related to the fuel cell power installation.

2 MATERIALS

2.1 General recommendations for materials

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

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

2.1.3 Austenitic stainless steel should be used for materials in contact with reformed fuel. Other materials may be approved after special consideration by PRS.

3 FUEL CELL POWER INSTALLATION DESIGN

3.1 General recommendations

3.1.1 A risk analysis shall be carried out for each new or changed concept or configuration of a fuel cell power installation to ensure that any hazards arising from the use of fuel cells that affect ship integrity are covered. Attention should be paid to installation, operation and maintenance hazards following any foreseeable failure.

3.1.2 The risk should be analyzed using acceptable and recognized risk analysis techniques. Factors such as 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 supply failure (blackout) should as a minimum be considered. The analysis should ensure that risks are eliminated wherever possible. Risks that cannot be eliminated should be mitigated as necessary.

3.1.3 The fuel cell power installation design should ensure that a single failure in the installation should not lead to an unacceptable loss of power.

3.1.4 The fuel cell power installation should be so designed that in case of emergency the recommended safety actions should not lead to an unacceptable loss of power.

3.2 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.

3.3 Exhaust gas and exhaust air outlets

3.3.1 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.

3.3.2 If the presence of explosive gases cannot be excluded, the exhaust air and/or exhaust gas should be arranged as an outlet from a hazardous area.

3.4 Purge gas outlets

Purge piping from the fuel cell power systems should be led separately to the open air and should be arranged as an outlet from a hazardous zone.

3.5 Fuel cell spaces

3.5.1 General recommendations

3.5.1.1 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.

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

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

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

3.5.1.5 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.

3.5.1.6 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).

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

3.5.1.8 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.

---

* See also IEC 60079-10-1:2020.

3.5.1.9 Fuel cell spaces containing fuel reformers should also comply with the recommendations relevant for the primary fuel.

3.5.1.10 Tanks for intermediate storage of primary or reformed fuel, if necessary, should be located outside the fuel cell space containing the fuel cells.

3.5.1.11 In principle, the surface temperature of components and pipes in the fuel cell space should never be above the auto-ignition temperature for the fuel used.

3.5.1.12 Fuel cell power systems with reformed fuel temperatures above the auto-ignition temperature should be subject to special consideration by risk analysis.

3.5.2 Location and access

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

3.5.2.2 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, complying with the *IGF Code*.

3.5.2.3 An air lock need not be used 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, drained of leakages and the inside atmosphere is confirmed gas-free.

3.5.2.4 These technical provisions include but are not limited to:

.1 all controls recommended for safe operation and gas freeing of the equipment and space should be provided for remote operation from outside the space;
.2 all parameters recommended 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 of fuel cell power system 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.

3.5.3 Atmospheric control of fuel cell spaces

3.5.3.1 General information

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.

3.5.3.2 Ventilation of fuel cell spaces

3.5.3.2.1 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.

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

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

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

3.5.3.2.5 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.

3.5.3.2.6 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.

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

3.5.3.2.8 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.

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

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

3.5.3.2.11 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.

3.5.3.3 Inerting the atmosphere of fuel cell spaces

Inerting may 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 *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 be only 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.

4 FIRE SAFETY

4.1 General recommendations on fire and explosion safety

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

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

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

4.2 Fire detection and alarm system

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

4.2.2 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.

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

---

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

4.3 Fire and explosion protection

4.3.1 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.

4.3.2 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.

4.3.3 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 system or to the surrounding space; and
.7 any other strategy accepted by PRS.

4.4 Fire extinguishing

4.4.1 A fixed fire-extinguishing system is recommended for fuel cell spaces.

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

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

4.5 Fire dampers

4.5.1 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.

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

5 ELECTRICAL SYSTEMS

5.1 General recommendations on electrical systems

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

5.1.2 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 IMO*

---

* 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*.

5.1.3 It should be ensured that the fuel cell can be disconnected from the electrical load at any load condition.

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

5.2 Hazardous area classification

5.2.1 General

5.2.1.1 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 5.2.2. In cases where the prescriptive provisions in 5.2.2 are deemed to be inappropriate, area classification according to IEC 60079-10-1:2020 should be applied with special consideration by PRS.

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

5.2.2 Definition of zones

5.2.2.1 Hazardous areas 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.

5.2.2.2 Hazardous areas zone 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.
- Areas on open deck, or semi-enclosed spaces on deck within 3 m of fuel cell exhaust air and exhaust gas outlets.
- 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.
- Areas on open deck or semi-enclosed spaces within 3 m of spaces in which other sources of release of hydrogen or reformed fuel are located.
- Fuel cell spaces.

5.2.2.3 Hazardous areas zone 2

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

6 CONTROL, MONITORING AND SAFETY SYSTEMS

6.1 General recommendations on control, monitoring and safety systems

6.1.1 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 IMO* for the performance level or equivalent.

---

* Refer to *ISO 13849-1:2015-06*

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

6.2 Gas or vapour detection

6.2.1 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.

6.2.2 The detection systems should continuously monitor the space for gas/vapour presence. 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.

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

6.3 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.

6.4 Bilge wells

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

6.5 Manual emergency shutdown

Manual activation of emergency shutdown (ESD) 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

6.6 Actions of the alarm system and safety system

6.6.1 Gas or vapour detection

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

6.6.1.2 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 necessary 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.

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

6.6.2 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.

6.6.3 Loss of ventilation

6.6.3.1 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 shutdown by process control should be considered on a case-by-case basis based on the risk analysis.

6.6.3.2 After the period has expired, a safety shut down should be carried out.

6.6.4 Emergency shutdown push buttons

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

6.6.5 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 enclosure should be protected from a coolant release. Consideration should be given to the safe removal of the coolant.

6.6.6 Fire detection

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

6.6.7 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.

6.7 Alarms

6.7.1 The alarm provisions in section 6.6, as well as Table 1, specify fuel cell power installation alarms.

6.7.2 Alarms additional to the ones provided in 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 detection	
Fuel cell spaces as per 6.6.2.1	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	

6.8 Safety actions

6.8.1 The safety action provisions in section 6.6 and Table 2 specify fuel cell power installations safety actions to limit the consequences of system failures.

6.8.2 Safety actions additional to the ones provided in 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 6.6.5	X	X		
40 % LEL inside fuel cell space (includes detection of hydrogen leaks as per 3.2.4)	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

7 ALTERNATIVE DESIGN

7.1 General

7.1.1 Appliances and arrangements of fuel cell power systems may deviate from those set out in this *Publication*, provided such appliances and arrangements meet the intent of the goal and functional recommendations concerned and provide an equivalent level of safety of the relevant sections.

7.1.2 The equivalence of the alternative design should be demonstrated as specified in *SOLAS Convention*, regulation II-1/55 and approved by PRS. 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 this *Publication*, are not allowed.

8 ON-BOARD OPERATION TESTS

8.1 Fuel piping systems

8.1.1 Reformed fuel piping systems should be tightness tested with hydrogen or an appropriate test gas to show that there is no leakage.

8.1.2 Valves in the fuel cell piping system should be leakage tested for the fuel used.

8.2 Testing of the complete fuel cell system

8.2.1 After being installed on board, all fuel cell power systems as well as control, monitoring and safety systems should be subjected to functional tests in accordance with the final acceptance and testing program.

8.2.2 All alarms specified in Table 1 in sub-chapter 6.7, and all safety functions specified in Table 2 in sub-chapter 6.8, should be tested to confirm that they are working properly.

8.2.3 Tests of the entire system should be performed under various appropriate load conditions (typically: "start", "normal operation", "full load", "load changes up/down").

8.2.4 If the fuel cell power installation constitutes the main propulsion system of the ship, during the tests it should be verified that the ship has adequate propulsion power in all manoeuvring situations.

Sources

1. CCC 7/WP.3, Annex 1 September 2021 – Interim Guidelines for the Safety of Ships Using Fuel Cell Power Installations.
2. IMO Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code).
3. CCC 5/3 Amendments to the IGF Code and Development of Guidelines for Low-Flashpoint Fuel.
4. Annex to MSC.1/Circ.1455 – Guidelines for the Approval of Alternative and Equivalents as provided for in Various IMO Instruments.
5. MSC.1/Circ.1647, June 2022 – Interim Guidelines for the Safety of Ships Using Fuel Cell Power Installations

The basic standards related to the subject of this *Publication*

1. IEC 62282-2-100:2020 Fuel cell technologies - Part 2-100: Fuel cell modules - Safety
2. IEC 62282-3-100:2019 Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety
3. IEC 62282-3-200:2015 Fuel cell technologies - Part 3-200: Stationary fuel cell power systems - Performance test methods
4. IEC 62282-3-201:2017 + AMD1:2022 CSV Fuel cell technologies - Part 3-201: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems
5. IEC 62282-3-300:2012 Fuel cell technologies - Part 3-300: Stationary fuel cell power systems - Installation
6. IEC 62282-3-400:2016 Fuel cell technologies - Part 3-400: Stationary fuel cell power systems - Small stationary fuel cell power system with combined heat and power output
7. IEC 62282-4-101:2014 Fuel cell technologies - Part 4-101: Fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APU) - Safety of electrically powered industrial trucks
8. IEC 62282-4-102:2017 Fuel cell technologies - Part 4-102: Fuel cell power systems for industrial electric trucks - Performance test methods
9. IEC 62282-5-100:2018 Fuel cell technologies - Part 5-100: Portable fuel cell power systems - Safety
10. IEC 62282-6-100:2010 + AMD1:2012 CSV Fuel cell technologies - Part 6-100: Micro fuel cell power systems - Safety
11. IEC 62282-6-200:2016 Fuel cell technologies - Part 6-200: Micro fuel cell power systems - Performance test methods
12. IEC 62282-6-300:2012 Fuel cell technologies - Part 6-300: Micro fuel cell power systems - Fuel cartridge interchangeability
13. IEC 62282-6-400:2019 Fuel cell technologies - Part 6-400: Micro fuel cell power systems - Power and data interchangeability
14. IEC 62282-7-2:2021 Fuel cell technologies - Part 7-2: Test methods - Single cell and stack performance tests for solid oxide fuel cells (SOFCs)
15. IEC 62282-8-101:2020 Fuel cell technologies - Part 8-101: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of solid oxide single cells and stacks, including reversible operation
16. IEC 62282-8-102:2019 Fuel cell technologies - Part 8-102: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of single cells and stacks with proton exchange membrane, including reversible operation
17. IEC 62282-8-201:2020 Fuel cell technologies - Part 8-201: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of power-to-power systems
18. IEC PAS 62282-6-150:2011 Fuel cell technologies - Part 6-150: Micro fuel cell power systems - Safety - Water reactive (UN Decision 4.3) compounds in indirect PEM fuel cells
19. IEC TS 62282-7-1:2017 Fuel cell technologies - Part 7-1: Test methods - Single cell performance tests for polymer electrolyte fuel cells (PEFC)
20. IEC TS 62282-9-101:2020 Fuel cell technologies - Part 9-101: Evaluation methodology for the environmental performance of fuel cell power systems based on life cycle thinking - Streamlined life-cycle considered environmental performance characterization of stationary fuel cell combined heat and power systems for residential applications

21. IEC TS 62282-9-102:2021 Fuel cell technologies - Part 9-102: Evaluation methodology for the environmental performance of fuel cell power systems based on life cycle thinking - Product category rules for environmental product declarations of stationary fuel cell power systems and alternative systems for residential applications
22. IEC/ISO 31010 Risk management – Risk assessment techniques
23. IEC 60812 Analysis techniques for system reliability –Procedure for failure mode and effects analysis (FMEA)
24. ASME B31.12, Hydrogen Piping and Pipelines
25. ISO 15649, Petroleum and natural gas industries – Piping