

Guidelines on
**Vessels with Fuel Cell Power
Installations**
(Provisional)

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Introduction

A fuel cell is a device that continuously converts an oxidizing fuel (hydrogen, methanol etc.) into electricity and water through an electrochemical reaction. The main distinction among fuel cell types is the electrolyte, and hence they are classified by the electrolyte (See Appendix A for a brief description of fuel cells). Fuel cells are different from batteries in that a battery stores energy, while a fuel cell generates energy by converting fuel. As long as there is fuel, the fuel cell continues to convert the energy into power.

Vessel power systems are typically comprised of redundant systems. This enables optimizing fuel consumption to the load demand and offers resilience in case of failure of a power system. Fuel cells nicely fit this requirement, as they may be combined into “modules”, and those modules can be operated efficiently and combined to meet the overall power requirement. Selection of the fuel cell stack and module designs (power, voltage, etc.) will depend on the target applications (e.g., power for emergency, or auxiliary, or propulsion, etc.)

These guidelines have been developed to provide requirements for vessels with fuel cell power installations. These guidelines provide requirements for the design, construction, testing and surveys of vessels equipped with fuel cells.

The goal of these guidelines is to provide criteria for the arrangement and installation of fuel cell power installations with at least the same level of safety 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 (Part 5, Chapter 35 of *IRS Rules and Regulations for the Construction and Classification of Steel Ships*) and provisions (e.g. *IRS Guidelines for Natural Gas fueled vessels for Coastal and Inland Waters*, *Guidelines on Methanol fueled vessels*) would be applicable in addition to these guidelines.

These guidelines are to be used in conjunction with the applicable Rules of IRS for construction and classification of vessels.

Vessels provided with fuel cell installations for propulsive power and auxiliary purposes in accordance with these guidelines may be assigned additional class notation **FC (Main)** and **FC (Auxiliary)** respectively. A qualifier indicating the particular low flashpoint fuel (methanol, ethanol, propane, butane, hydrogen) used in the fuel cell will be added to the notation, e.g: **FC (Main) – Hydrogen**.

There may be cases where vessels are used in fuel cell-battery hybrid configurations. In such cases, the requirements of *IRS Guidelines on Battery Powered Vessels* and Classification Note: *Approval of Lithium-ion Battery Systems*, are also to be applied, as relevant and applicable.

In general, the recommendations/ requirements in these guidelines are applicable to all types of fuel cell configurations and fuels. Specific recommendations/ requirements (as indicated in this document) may be taken cognisance of, for particular fuels/ fuel cell configurations.

Section 1

General

1.1 Application

1.1.1 These guidelines are applicable to vessels fitted with fuel cell power installations which are fuelled by low flashpoint fuels.

1.2 Goal

1.2.1 These guidelines are intended to provide safe and reliable delivery of electrical and/or thermal energy through the use of fuel cell technology.

1.3 Functional requirements

These guidelines are related to the goals and functional requirements of the IGF Code and the risk assessment approach. In particular, the following apply:

1.3.1 The safety, reliability and dependability of the systems is to 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.

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

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

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

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

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

1.3.7 System components are to be protected against external damages.

1.3.8 Sources of ignition in hazardous areas are to be minimized to reduce the probability of fire/ explosions.

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

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

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

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

1.3.13 Fixed leakage detection suitable for all spaces and areas concerned are to be arranged.

1.3.14 Fire detection, protection and extinction measures appropriate to the hazards concerned are to be provided.

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

1.3.16 The technical documentation is to 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.

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

1.3.18 Safe access is to be provided for operation, inspection and maintenance.

1.4 Definitions

For the purpose of these 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.

1.4.1 *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.

1.4.2 *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.

1.4.3 *Fuel cell stack* is an 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.

1.4.4 *Fuel cell module* is an assembly incorporating one or more fuel cell stacks and other main and, if applicable, additional components, which is intended to be integrated into a power system.

1.4.5 *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.

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

1.4.7 *Fuel preparation space* is any space or room containing equipment for fuel preparation purposes, such as fuel pumps, fuel valve train, heat exchangers and filters.

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

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

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

1.4.11 *Primary Fuel* is fuel supplied to the fuel cell power system.

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

1.5 Alternative designs

1.5.1 These 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 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 is to be demonstrated as specified in SOLAS Regulation II-1/55 and approved by the Administration. However, 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 guidelines; will not be permissible.

1.5.4 IRS *Guidelines on Alternative and Risk Based Design Evaluation* may also be referred.

1.6 Risk Assessment

1.6.1 A risk assessment is to be conducted to identify risks arising from the use of fuels (methyl/ethyl alcohol, hydrogen, etc.) affecting the structural strength or the integrity of the vessel, safety of crew on board, and preservation of the environment. Consideration is to be given to the hazards associated with physical layout, operation and maintenance following any reasonably foreseeable failure. The risks are to be analyzed using acceptable and recognized risk analysis techniques. Loss of function, component damage, fire, explosion and electric shock are to be considered as a minimum. The analysis should identify risks that can be eliminated wherever possible. Risks which cannot be eliminated are to be mitigated as necessary. Identification of risks, and the means by which they are mitigated, are to be documented to the satisfaction of IRS and to the flag Administration if required. Risk assessment may be carried out in accordance with recognised standards such as ISO 31010:2009.

1.6.2 A risk analysis of the fuel cell installation systems is to be performed to assess the consequences of a failure affecting the systems and/or a gas leakage. The required analysis can be a FTA, FMEA, HAZOP analysis, a combination of techniques or another type of analysis.

Note: The following points need to be considered:

- The risk analysis should be based on the single failure concept, which means that only one failure needs to be considered at a time.
- Both detectable and non-detectable failures.
- Consequences failures, i.e. failures of any component directly caused by a single failure of another component.

1.6.3 The scope of the risk analysis should be as follows:

- (i) Identify all the possible failures in the concerned systems which could lead to a loss of the designated/required function;
- (ii) Evaluate the consequences;
- (iii) Identify the method of failure detection;
- (iv) Identify the corrective measures in the system design and operations
 - a. such as redundancies or safety devices, monitoring or alarm provisions which permit restricted operation of the system;
 - b. such as initiation of the redundancy or activation of an alternative mode of operation.

1.6.4 The fuel cell power system risk assessment report is to be submitted for review, and as a minimum is to address the following issues, as relevant and applicable:

- High energy collision with potential to penetrate a Liquid Hydrogen tank
- Rupture of compressed hydrogen/ liquefied hydrogen tank containment system
- Leakage of hydrogen gases, any fuels gases
- Internal leakage in fuel cell module
- Issues associated with storage of hydrogen as fuel, such as vicinity of other equipment, corrosion, extreme high temperature, etc.
- Exothermic reaction of reformer material
- Failure of fuel pressure reduction
- Failure of the electrical power output conditioning system
- Thermal runaway of onboard energy buffer
- Loss of inert gas system
- Toxicity potential and risk of oxygen deficiency or other negative impacts on crew health due to fuels and inert gases
- Safe handling, stowage, marking and carriage of flammable, toxic, and other dangerous substances
- Sufficient capacity of each drip tray to provide that the maximum amount of spill can be handled
- Special consideration of closed or semi-enclosed bunkering station with mechanical ventilation;
- Likely causes and consequences of release of fuel. The consequences of any release of fuel are to be minimized, while providing safe access for operation and inspection
- Safe handling and containment arrangement for excess fuel (e.g. in the fuel cell stack) where there is no recirculation to the fuel processing system
- Risk of electrical shock (touching of fuel cell plates)
- Permanently installed gas detectors at ventilation inlets to accommodation and machinery spaces
- Arrangement of any fixed and/or portable fire extinguishing systems
- Gas detection systems
- Control, monitoring and safety systems
- Black-out
- Arrangement and the number of personnel protective equipment (i.e., eyewash, safety shower, safety glasses, canister mask, etc.)
- Risks associated with gases “heavier than air” (eg: propane, butane or other gases)

1.6.5 As a guidance, risks associated with using hydrogen as a fuel in fuel cells and possible mitigation measures are indicated in Appendix B.

1.7 Fuel Cell Certification

1.7.1 Fuel cell power systems are to be certified at the manufacturer’s facility. The Table below provides certification requirements for certain equipment and components of the fuel cell system.

Table 1.7.1 : Certification Requirements – Fuel Cells

| Equipment/ Component | Product Certification | Requirements/ Standards |
|---|------------------------------|--|
| Fuel Cell Modules | Required | IEC 62282-2-100:2020 |
| Fuel cell power system | Required | IEC 62282-3 series |
| Pressure Vessels | Required | Pt 4, Ch 5 of IRS Rules (Main Rules) |
| Pipes, Valves and Fittings | Required | Pt 5, Ch 4 of IRS Rules (Main Rules) |
| Hydrogen Storage Tank | Required | Pt 4, Ch 5 & Pt.5, Ch. 4 of IRS Rules (Main Rules) |
| Fuel Cell Control and Monitoring System | Required | IEC 62282-3 series |
| Electrical Equipment | Required | Pt 4, Ch 8 of IRS Main Rules |
| Gas detection system | Required | Recognised national/ international standards |
| Fire detection and alarm system | Required | FSS Code |
| Fire extinguishing system | Required | FSS Code |
| Bunker Hoses ¹ | Required | Recognised national/ international standards |
| Note: | | |
| 1. Where used, bunker hose assemblies are to be burst tested to an international standard to demonstrate they are able to withstand a pressure not less than five (5) times its design pressure without indication of failure or leakage subject to the satisfaction of the attending Surveyor. | | |

1.8 Plans and Documentation

1.8.1 In general, following is the list of plans and documentation to be submitted to IRS for review. There could be some differences depending upon the type of fuel, fuel cell chemistry, etc.:

- (i) Description of the process and function of the fuel cell system, including fuel cell design and capacity calculations
- (ii) Piping and instrumentation diagrams, with block circuit diagrams of the overall system, including parts lists or equipment lists
- (iii) Technical documents of the components, including the fuel cell stacks themselves (descriptions, specifications, verification of suitability according to existing standards and rules, approvals and inspection certificates)
- (iv) General arrangement of the machinery spaces containing the gas utilization equipment and of the gas storage units, with description of the classification of hazardous areas
- (v) Risk analysis (FTA, FMEA, HAZOP analysis, or another type of analysis). The document is to identify and evaluate the hazards associated with each function of the fuel cell power system throughout its lifecycle. The risk assessment is to also include the necessary parameters for the safe and effective operation of the control, monitoring and safety systems. The risk assessment is also to take into account aspects indicated at 1.6.4, 2.8.1, 2.10.1, 2.11.3, 3.5.2, 4.2.4, 4.2.5, 4.4.2, 5.2.1, 5.8.3, 5.11.3 and 5.11.7.

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- (vi) Control, monitoring and safety systems
 - (vii) Fire detection and extinguishing systems
 - (viii) Single line diagram for Fuel cell power system
 - (ix) Emergency shutdown arrangements (for bunkering system, fuel supply system, disconnection arrangements, etc.)
 - (x) Hazardous area classification plan
 - (xi) List of all electrical equipment installed in the hazardous areas.
 - (xii) Design data, piping and instrumentation diagram and sizing calculation of the liquid/ gas storage and piping systems
 - (xiii) Fuel properties (storage pressure, temperature, LFL, toxicity, corrosivity and any other important safety related characteristics)
 - (xiv) Operation and maintenance manual of the fuel cell installation (refer Cl. 1.9)
 - (xv) Fuel bunkering station arrangements
 - (xvi) Fuel cell physical environment and operating conditions including the following:
 - a. Electrical power input, output
 - b. Fuel input: type, volume, rate, temperature, supply pressure
 - c. Water input (when required for the operation): quantity, temperature, supply pressure
 - d. Vibration, shock and bump limits
 - e. Guideline for handling, transportation, and storage
 - f. System purging
 - g. Fuel characteristics (storage pressure, temperature, LFL, toxicity, corrosivity and any other important safety related characteristics)
 - (xvii) Maintenance schedule and procedures for fuel cell replacement
 - (xviii) General arrangement of the fuel containment system
 - (xix) Fuel containment system structure (including the installation of supports)
 - (xx) Loading and unloading systems, venting systems, and gas-freeing systems, as well as a schematic diagram of the remote controlled valve system
 - (xxi) Technical fire protection file (refer Cl. 3.4.4)
 - (xxii) Ventilation system
 - (xxiii) Testing/Trials Plan: The test plan is to identify all equipment, fuel cell power systems and the recommended method of performing the tests or trials.

1.9 Operation and Maintenance Manual

1.9.1 An operation and maintenance manual detailing procedures for set-up and use of the fuel cell power system is to be provided. Particular emphasis is to be given to safety measures and any anticipated improper methods of operation.

1.9.2 In case of programmable fuel cell systems, detailed information on methods of programming, equipment required, program verification and additional safety procedures (where required) are to be provided.

1.9.3 The manual is to include, but not be limited to the operational procedures for the loading, storage, operation, maintenance, and inspection of systems for gas or liquid fuels to minimize the risk to personnel, together with details of required personal protective equipment and the occupational health hazards relevant to the use of gas as a fuel.

1.9.4 The manual is to clearly indicate and/or include, but is not to be limited to, the following:

- Start-up and operational procedure
- Fuel cell module specification and general characteristics
- Sequence of operation(s)
- Frequency of inspection
- Normal and emergency shut-down procedures
- Storage procedure and conditioning
- Bunkering procedure
- Maintenance and repair procedures
- Functional testing plan for automation and control system
- Maintenance and function testing plan details of all components and instrumentations
- General notes and prohibited operation; information on the physical environment (for example, range of ambient temperatures for operation, vibration, noise levels, atmospheric contaminants) where appropriate
- Procedures for making areas safe for hot work on or near fuel systems
- Installation procedure (including handling, transportation, preparation, fixing method of the module, connection method of gas and coolant piping, connection method of the electric line and sensors and circuit diagram(s))
- Bunkering procedure including the maximum transfer rate at all stages and volume to be transferred
- Pre-bunkering operations/verification all necessary requirements and documented in the bunker safety checklist
- Communication devices used in bunkering

Section 2

Design Principles for Fuel Cell Power Installations

2.1 Fuel cell spaces

2.1.1 Fuel cell space concept

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

2.1.1.2 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.

2.1.1.3 Fuel cell spaces (area classification according to Cl. 4.2.2) are considered as hazardous zone 1 and all electrical equipment are to be certified for zone 1.

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

2.1.1.5 In specific cases where IRS/ the Administration accepts inerting according to Cl. 2.3.3, 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 other power supply systems is to take place and a controlled shutdown of the fuel cell and the affected fuel supply system is to be initiated in order thereby avoiding damage to the fuel cell power system.

2.1.2 The design of fuel cell power systems is to comply with recognised industry standards, such as IEC 62282-2:-100:2020, IEC 62282-3-100:2019.

2.2 Arrangement and access

2.2.1 Fuel cell power installations are to 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 is to 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 are to be provided.

2.2.4 Means are to 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 are to 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 are to 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 spaces boundaries are to be gastight towards other enclosed spaces in the vessel.

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

2.2.9 Fuel cell spaces are to be designed to safely contain fuel leakages and be provided with suitable leakage detection systems.

2.2.10 Fuel cell spaces are to be arranged to avoid the accumulation of hydrogen-rich gas by having simple geometrical shape and no obstructing structures in the upper part.

2.2.11 Fuel cell spaces containing fuel reformers are also to comply with the requirements relevant for the primary fuel.

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

2.2.13 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, drained of leakages and the inside atmosphere is confirmed gas-free.

2.2.14 These provisions include but are not limited to:

- .1 all controls required for safe operation and gas freeing of the equipment and space are to be provided for remote operation from outside the space;
- .2 all parameters required for safe operation and gas freeing are to be remotely monitored and alarms are to be given;
- .3 the space openings are to be equipped with an interlock preventing operation with the space open;
- .4 the spaces are to be provided with suitable fuel leakage collection and draining arrangements for remote operation from outside the space; and
- .5 provisions are to 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

2.3.1.1 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 are to 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 are to be equipped with an effective mechanical ventilation system to maintain under pressure 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 is to be sufficient to dilute the average gas/ vapour concentration below 25% of the flammable range in all maximum probable leakage scenarios due to technical failures.

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

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

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

2.3.2.7 In case of failure of one fan, automatic change-over to another fan is to be provided and indicated by an alarm.

2.3.2.8 In case of loss of ventilation or loss of negative pressure in the fuel cell space the fuel cell power system is to 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 are to 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 are to be taken from non-hazardous areas located at least 1.5 m away from the boundaries of any hazardous area.

2.3.2.11 Ventilation air outlets from fuel cell spaces are to 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.

2.3.2.12 In general, the requirements of Part 5, Chapter 4, Section 12 of the *IRS Rules and Regulations for the Construction and Classification of Steel Ships* are to be complied with, for design of ventilation fans that serve spaces where vapours may be present.

2.3.3 Inerting of fuel cell spaces

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

.1 protection by inerting is only acceptable where a fuel cell space is not possible to be entered during inerting and sealing arrangements are to ensure that leakages of inert gas to adjacent spaces are prevented;

.2 the inerting system complies with Part 6, Chapter 8, Section 15 and Part 5 Chapter 4, Section 6, Cl. 6.13 and 6.14 of *IRS Rules and Regulations for the Construction and Classification of Steel Ships*;

.3 the pressure of inerting media is always to 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, etc.) is to activate a controlled shut-off of the fuel supply;

.5 fuel cell space is to 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 is to 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 is not to be operable under ongoing maintenance or inspection.

2.4 Materials

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

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

2.4.3 In general, materials used in gas tanks, gas piping, process pressure vessels and other components in contact with cryogenic liquids or gases are to be in accordance with Part 5 Chapter 4, Section 6 of the *IRS Rules and Regulations for the Construction and Classification of Steel Ships*.

2.4.4 Materials used in all components in contact with hydrogen are to be resistant to hydrogen embrittlement, hydrogen attack, hydriding, porosity, permeation and diffusion. A material is not to be used unless data is available showing that it is suitable for the planned service conditions. In case of any doubt the material can be subjected to hydrogen embrittlement susceptibility testing (in accordance with ISO 11114-4) to evaluate material suitability before use.

2.4.5 Guidance on suitability of certain materials for hydrogen service is as follows:

| Table 2.4: Suitability of certain materials in hydrogen service | | | |
|---|--------------------------------|-------------------------------|--|
| Materials | Gaseous H ₂ service | Liquid H ₂ service | Remarks |
| Metals | | | |
| Aluminium and alloys | Yes | Yes | Negligibly susceptible to hydrogen embrittlement |
| Copper and its alloys (such as brass, bronze and Cu-Ni) | Yes | Yes | |
| Iron (cast, grey, ductile) | No | No | |
| Nickel and alloys (Monel and Inconel) | Evaluation needed ¹ | Evaluation needed | Evaluation needed. Susceptible to hydrogen embrittlement |
| Titanium and its alloys | Evaluation needed | Evaluation needed | |
| Austenitic steel with >7% nickel (e.g. 304, 304L, 308, 316, 321, 347) | Yes | Yes | May make martensitic conversion if stressed above yield point at low temperature. |
| Carbon steel (e.g. 1020 and 1042) | Yes | No | Evaluation needed. Susceptible to hydrogen embrittlement. Too brittle for cryogenic service. |
| Low alloy steel (e.g. 4140) | Evaluation needed | No | |
| Martensitic stainless steel (e.g. 410 and 440C) | Evaluation needed | Evaluation needed | Evaluation needed. Susceptible to hydrogen embrittlement. |

| | | | |
|---|-------------------|-----|--|
| Nickel steel (e.g. 2.25%, 3.5%, 5% and 9% Ni) | Evaluation needed | No | Ductility lost at liquid hydrogen temperature. |
| Non-Metals | | | |
| Chloroprene rubber | Yes | No | Too brittle for cryogenic service. |
| Polyester fibre (Dacron) | Yes | No | |
| Nitrile rubber | Yes | No | |
| Polyamides (nylon) | Yes | No | |
| Polytetrafluoroethylene (PTFE) | Yes | Yes | |
| Polychlorotrifluoroethylene (Kel-F) | Yes | Yes | |
| Note: | | | |
| 1. Evaluation needed to determine if the material is suitable for the use conditions. | | | |

2.5 Piping arrangements

2.5.1 All pipes containing reformed fuel for fuel cell power systems, where fitted, are:

- .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.

2.5.2 Piping design

2.5.2.1 In general, the requirements in Part 5, Chapter 4, Section 5 of the *IRS Rules and Regulations for the Construction and Classification of Steel Ships* are to be complied with for design of the piping systems.

2.5.3 Hydrogen Piping Requirements

2.5.3.1 Hydrogen piping systems are to be designed in accordance with recognized standards. The fabrication, assembly, erection, inspection, examination and testing of hydrogen piping systems are to be performed in accordance with a recognized standard acceptable to IRS (such as ASME B31-12, Hydrogen Piping and Pipelines).

2.6 Exhaust gas and exhaust air

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

2.7 Fuel Cell Modules

2.7.1 The fuel cell module is to be designed, type approved and/ or unit certified for compliance with IEC 62282-2 or other equivalent recognized standards.

2.7.2 In addition, the fuel cell module is to comply with the appropriate marine environmental conditions specified in 2.8.1.1

2.8 Fuel Cell Power Systems

2.8.1 General

.1 The fuel cell power systems are to be suitable for inclinations and environmental conditions indicated in Table 1.7.1 of Part 4, Chapter 1 of the *IRS Rules and Regulations for the Construction and Classification of Steel Ships* and Classification Note : *Type Approval of Electrical Equipment used for Control, Monitoring, Alarm and Protection Systems for Use in Ships*.

.2 Accessible parts of the fuel cell power system are to have no sharp edges, sharp angles or rough surfaces likely to cause injury.

.3 The fuel cell power system, components and fittings are to be designed and constructed so that they are stable enough, under the operating conditions for use without risk of overturning, falling or unexpected movement. Otherwise, appropriate means of support are to be incorporated.

.4 The moving parts of the fuel cell power system are to be designed, built and arranged to avoid hazards or, where hazards persist, fixed with guards or protective devices in such a way to prevent all risk of contact.

.5 The fuel cell power system is to be designed, constructed and/or equipped so that risks due to gases, liquids, dust or vapours released during the operation or maintenance of a fuel cell power system are avoided.

.6 All parts are to be securely mounted or attached and rigidly supported. The use of shock-mounts is permitted when suitable for the application.

.7 All safety shutdown system components, whose failure may result in a hazardous event, as identified by the risk analysis, are to be certified or separately tested for their intended usage.

2.8.2 Standards for fuel cell power systems

2.8.2.1 The following standards may be referred for the functional safety and performance level of fuel cell power systems:

(a) IEC 62282-3-100:2019; stationary fuel cell power systems - safety

(b) IEC 62282-3-200:2015; stationary fuel cell power systems – Performance test methods

2.9 Fuel Preparation Rooms and Pumps

2.9.1 Fuel preparation rooms are to be located outside Category A machinery spaces with ventilation of at least 30 air changes per hour. These rooms are to be gas tight and liquid tight to the surrounding enclosed spaces and vented to open air.

2.9.2 Hydraulically powered pumps that are submerged in fuel tanks are to be arranged with double barriers preventing the hydraulic system serving the pumps from being directly exposed to fuels. The double barrier is to be arranged for detection and drainage of eventual fuel leakage.

2.9.3 All pumps in the fuel system are to be protected against running dry (i.e., protected against operation in the absence of fuel or service fluid).

2.9.4 All pumps which are capable of developing a pressure exceeding the design pressure of the system are to be provided with relief valves. Each relief valve is to be in closed circuit (i.e., arranged to discharge

back to the piping upstream of the suction side of the pump and to effectively limit the pump discharge pressure to the design pressure of the system).

2.9.5 Fuel preparation rooms are to be fitted with an effective mechanical forced ventilation system of extraction type. During normal operations the ventilation capacity is to provide at least 30 air changes per hour.

2.9.6 The number and power of the ventilation fans are to be such that the capacity is not reduced by more than 50% if a fan with a separate circuit from the main switchboard, or emergency switchboard, or a group of fans with common circuit from the main switchboard or emergency switchboard is inoperable.

2.9.7 Ventilation systems for fuel preparation rooms and other fuel handling spaces are to be in operation when pumps or other fuel treatment equipment are working.

2.10 Fuel Tanks and Fuel Containment Systems

2.10.1 General

.1 Propulsion and power generation arrangements, together with fuel supply systems are to be arranged so that a failure in fuel supply does not lead to an unacceptable loss of power.

.2 Fuel tanks are to be located such that the probability of damage following a collision or grounding is minimized taking into account the safe operation of the vessel and other hazards. Consideration for fuel tank location may be made using risk assessment, and is to cover aspects such as protective location, fire protection, life-saving appliances and evacuation arrangements.

.3 Tanks containing fuel are not to be located within accommodation spaces or machinery spaces.

.4 Fuel tanks located on open decks are to be protected against mechanical damage.

.5 Fuel tanks on open decks are to be surrounded by coamings, with spills collected in a dedicated holding tank (e.g. for liquid fuels).

.6 Integral fuel tanks are to be surrounded by protective cofferdams, except on those surfaces bound by bottom shell plating, other fuel tanks or the fuel preparation room.

.7 Where practicable, fuel tanks and surrounding cofferdams are to have suitable access from the open deck for gas-freeing, cleaning, maintenance and inspection.

.8 If compliance with 2.10.1.7 (i.e. access from open deck) is not practicable, the entry space is to comply with the following:

- (a) Entry space is to be fitted with an independent mechanical extraction ventilation system, providing a minimum of 10 air changes per hour. A low oxygen alarm and a gas detection alarm are to be fitted.
- (b) Entry space is to have sufficient open area around the fuel tank hatch for efficient evacuation and rescue operation.
- (c) Direct entry from accommodation spaces, service spaces, control stations and machinery spaces are not permitted.
- (d) Entry from cargo spaces may be accepted depending upon the type of cargo if the area is cleared of cargo and no cargo operations are undertaken during tank entry.

.10 For safe access, horizontal hatches or openings to or within fuel tanks or surrounding cofferdams are to have a minimum clear opening of 600 mm by 600 mm that allows the hoisting of an injured person through it. For access through vertical openings providing main passage through the length and breadth within fuel tanks and cofferdams, the minimum clear openings are not to be less than 600 mm by 800 mm at a height of not more than 600 mm from bottom plating unless gratings or footholds are provided. Smaller openings may be **accepted** provided evacuation of an injured person through it can be demonstrated.

.11 Detailed instruction manuals are to be provided onboard covering operations, safety and maintenance requirements and occupational health hazards relevant to the use of a particular fuel. Fuel tank operation aspects of the manuals are to include but are not to be limited to: instructions for bunkering, stripping tanks, inerting, warming up/cooling down procedures, venting and means for avoiding stratification/rollover, as applicable.

2.10.2 Independent Fuel Tanks

.1 Independent fuel tanks are to be secured to the vessel's structure. The arrangement for supporting and fixing the tanks is to be designed for the maximum expected static and dynamic loads as well as the maximum expected acceleration loads, taking into account the vessel characteristics and the position of the tanks.

.2 Independent tanks may be accepted on open decks or in enclosed spaces.

.3 The area around independent fuel tanks is to be sufficient to carry out evacuation and rescue operations.

.4 Independent tanks are to be fitted with the following:

(a) Mechanical protection of the tanks depending on location and cargo operations

(b) Drip tray arrangements for leak containment and water spray systems for emergency cooling, if located on an open deck.

(c) If located in an enclosed space, the space is to meet the requirements of Cl. 2.3.2 and Section 3.

.5 Independent tanks are to be constructed and tested in accordance with the requirements of Part 5, Chapter 4 of *IRS Rules and Regulations for the Construction and Classification of Steel Ships*.

2.10.3 Portable Fuel Tanks

.1 The design of the tanks is to comply with 2.10.2 above.

.2 Portable tanks are to be fitted with the following:

(a) Mechanical protection of the tanks depending on location and cargo operations

(b) Drip tray arrangements for leak containment and water spray systems for emergency cooling, if located on an open deck.

(c) If located in an enclosed space, the space is to meet the requirements of Cl. 2.3.2 and Section 3.

.3 Portable fuel tanks are to be secured to the deck while connected to the vessel's systems. The arrangement for supporting and fixing the tanks are to be designed for the maximum expected static and

dynamic loads as well as the maximum expected acceleration loads, taking into account the vessel characteristics and the position of the tanks.

.4 Consideration is to be given to the vessel's strength and the effect of the portable fuel tanks on the vessel's stability.

.5 Connections to the vessel's fuel piping systems are to be made by means of approved flexible hoses suitable for the fuel or other suitable means designed to provide sufficient flexibility.

.6 Arrangements are to be provided to limit spilled fuel in case of inadvertent disconnection or rupture of the non-permanent connections.

.7 The pressure relief system of portable tanks is to be connected to a fixed venting system.

.8 Control and monitoring systems for portable fuel tanks are to be integrated in the vessel's control and monitoring system. Safety system for portable fuel tanks are to be integrated in the vessel's safety system (e.g., shutdown systems for tank valves, leak/vapour detection systems).

.9 Safe access to tank connections for the purpose of inspection and maintenance are to be provided.

.10 When connected to the vessel's fuel piping system:

- (a) Each portable tank is to be capable of being isolated at any time
- (b) Isolation of one tank is to not impair the availability of the remaining portable tanks
- (c) The tank is not to exceed its filling limits

2.10.4 Fuel tanks are to be monitored against overfilling as indicated in Section 5.

2.11 Fuel Supply System to Consumers

2.11.1 The fuel supply system is to be independent and separate from other piping systems.

2.11.2 The piping system for fuel transfer is to be designed so that a failure of one barrier will not lead to a leak from the piping system into the surrounding area, causing danger to the persons on board, the environment or the vessel.

2.11.3 The fuel supply system is to be arranged so that the consequences of any release of fuel will be minimized, while providing safe access for operation and inspection. The causes and consequences of any leakage are to be considered within the risk assessment.

2.11.4 In general, fuel piping is to be located in well-ventilated spaces, and as far as practicable to be fully welded.

2.11.5 Fuel piping is not to pass directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in SOLAS. In cases where fuel piping needs to be routed through accommodation spaces, the fuel piping is to be double walled and led through a dedicated duct. The ducts are to be of substantial construction and be gas tight and watertight.

2.11.6 All piping containing fuel passing through enclosed spaces are to be double walled. Such double walled piping is not required in cofferdams surrounding fuel tanks, or in spaces or units not normally accessed or fuel preparation-rooms or other fuel treatment spaces considered as hazardous.

2.11.7 The outer pipe or ducts are to be gas tight and watertight.

2.11.8 When liquid hydrogen pipe is used the vacuum insulated pipe type is to be considered provided that its design and installation is in accordance with recognized standards.

2.11.9 The outer pipe in the double walled fuel pipes is to be dimensioned for a design pressure not less than the maximum working pressure of the fuel pipes. As an alternative, the calculated maximum built up pressure in the duct in the case of an inner pipe rupture may be used for the dimensioning of the duct.

2.11.10 The annular space between inner and outer pipe are to have mechanical ventilation of an under-pressure type, with a capacity of a minimum 30 air changes per hour, and be ventilated to open air. Appropriate means for detecting leakage into the annular space are to be provided. The double wall enclosure is to be connected to a suitable draining tank allowing the collection and the detection of any possible leakage.

2.11.11 Inerting of the annular space may be accepted as an alternative to ventilation. Appropriate means of detecting leakage into the annular space are to be provided. Suitable alarms are to be provided to indicate a loss of inert gas pressure between the pipes.

2.11.12 The ventilation system for double wall piping and ducts is to be independent of all other ventilation systems.

2.11.13 The ventilation inlet for the double wall piping or duct is to always be located in a non-hazardous area, in open air, away from ignition sources. The inlet openings are to be fitted with a suitable wire mesh guard and protected from ingress of water.

2.12 Air Locks

2.12.1 Where provided, air locks are to comply with the requirements of Cl. 2.8 of IRS Classification Note: *Gas Fuelled Vessels for Coastal and Inland Waterways*

2.13 Bunkering Arrangements

2.13.1 General

.1 Bunkering arrangements are to be designed such that any leakage from the piping system cannot cause danger to persons onboard, the environment (such as spills onto water, and air emissions including pollutants, toxic gases. etc.) or the vessel.

2.13.2 Bunkering Station

.1 The bunkering station is to be located on the open deck so that sufficient natural ventilation is provided. Mechanical ventilation requirements for closed or semi-enclosed bunkering stations would be specially considered.

.2 Entrances, air inlets and openings to accommodation, service and machinery spaces and control stations are not to face the bunkering connection.

.3 Closed or semi-enclosed bunkering stations are to be surrounded by gastight boundaries against enclosed spaces.

.4 Bunkering lines are not to pass directly through accommodation, control stations or service spaces. Bunkering lines passing through non-hazardous areas in enclosed spaces are to be double walled or located in gas-tight ducts.

.5 Arrangements are to be made for safe management of fuel spills. Coamings and/or drip trays are to be provided below the bunkering connections together with a means of safely collecting and storing spills. This could be a drain to a dedicated holding tank equipped with a level indicator and alarm. Where coamings or drip trays are subject to rainwater, provisions are to be made to drain rainwater overboard.

.6 Showers and eye wash stations for emergency usage are to be located in close proximity to areas where the possibility for accidental contact with fuel exists. Emergency showers and eye wash stations are to be operable under all ambient conditions.

2.13.3 Bunkering system

.1 Fuel bunker piping arrangements between the bunkering manifold and the fuel storage tank are to be in accordance with the requirements of Cl. 2.5.

.2 Means are to be provided for draining any fuel from the bunkering pipes upon completion of operation.

.3 Means are to be provided to inert bunker lines and make them gas free.

.4 In the bunkering line, as close to the connection point as possible, there is to be a manually operated stop valve and a remotely operated shutdown valve arranged in series. Alternatively, a combined manually operated and remote shutdown valve may be provided. Operation of this remotely operated valve is to be possible from the bunkering control station.

.5 Where bunkering pipes are arranged with a crossover, suitable isolation arrangements are to be provided that fuel cannot be transferred inadvertently to the vessel side not in use for bunkering.

.6 The bunkering manifold is to be designed to withstand the external loads encountered during bunkering. The connections at the bunkering station are to be of dry-disconnect type and equipped with an additional safety dry break-away coupling or self-sealing quick release. The couplings are to be of a standard type.

2.13.4 Bunkering Hoses

.1 Where fuel hoses are to be carried on board, arrangements are to be made for safe storage of the hoses. Hoses are to be stored on the open deck or in a storage room with an independent mechanical extraction ventilation system, providing a minimum of 6 air changes per hour.

.2 Means are to be provided for draining any excess fuel from the bunkering hoses upon completion of fuelling.

.3 Bunker hoses are to be suitable for the fuel used and certified to a minimum bursting pressure of 5 times the normal working pressure.

2.13.5 Emergency Shutdown System

.1 The vessel is to be fitted with a bunkering Emergency Shutdown (ESD) system operable from both the vessel and the bunker supply facility. This is to allow a rapid and safe shutdown of the bunker supply system without the release of liquid or vapour.

2.13.6 Control and Monitoring

.1 The control and monitoring arrangements for the bunkering system are to be provided in accordance with Section 5

Section 3

Fire Safety

3.1 General

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

3.2 Structural Fire Protection

3.2.1 Fuel preparation rooms are to be regarded as machinery space of category A according to SOLAS Chapter II-2 for fire protection spaces.

3.2.2 A fuel cell space (FCS) is to be bounded by "A-60" class divisions on all sides adjoining control stations, evacuation stations, escape routes, accommodation spaces, stairways, corridors and machinery spaces. Where this is deemed to be impracticable, IRS/ the Administration may approve alternative boundary designs that provide for an equivalent level of safety.

3.2.3 The fuel tank cofferdam boundaries facing high fire risk spaces such as machinery spaces and similar are to be separated by a cofferdam of at least 900 mm with insulation of A-60 class.

3.2.4 The bunkering station is to be separated by A-60 class divisions between Category A machinery spaces, accommodations, control stations and high fire risk spaces except for spaces such as tanks, voids, auxiliary machinery spaces of little or no fire risk, and sanitary and similar spaces where the boundary may be reduced to class A-0.

3.3 Fire detection

3.3.1 A fixed fire detection and fire alarm system complying with the FSS Code is to be provided for all compartments containing the specific fuel system.

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

3.3.3 Fuel cell spaces are to be fitted with suitable fire detectors. Smoke detectors alone are not considered sufficient for rapid detection of a fire when gaseous fuels are used. Recommendations in ISO/TR 15916:2015 may be taken cognizance of, whilst selecting suitable fire detectors.

3.3.5 The detection of hydrogen fire is to be specifically addressed, since hydrogen fire produces no smoke, little heat radiation and an almost invisible flame in daylight.

3.3.6 Some important considerations for selection of hydrogen fire detectors are as follows:

- detection distance and area covered
- susceptibility false alarms from sources such as sun, lightning, welding, lighting sources and background flare stacks
- response time
- sensitivity to appropriate radiation spectrum

3.4 Fire and explosion protection

3.4.1 Fuel cell spaces separated by a single bulkhead are to 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. Documentation showing that the bulkhead has sufficient strength to withstand a worst-case explosion is to be submitted for review.

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

3.4.3 The probability of a gas accumulation and explosion in fuel cell spaces could be minimized by one or more of the below strategies, as appropriate for the applied technology:

- .1 purging the fuel cell power system before initiating the reaction;
 - .2 balancing the air-to-fuel ratio in operation;
 - .3 purging the system as necessary after shutdown;
 - .4 providing fault monitoring sensors to maintain the reaction process within the design limits;
 - .5 providing failure monitoring in the fuel cell fuel containment systems;
 - .6 monitoring potential contamination of air into fuel cells fuel lines, or fuel cells fuel into air pipes;
 - .7 monitoring pressures and temperatures; and
 - .8 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.
- .7 any other strategy proposed by the manufacturer to the satisfaction of IRS/ Administration

3.4.4 For each fuel cell system installed onboard, a Technical Fire Protection File is to be provided by the manufacturer, to be approved by IRS/ the Administration. The document is to cover all aspects relevant to purging of the system, before and after operation, balancing of the air-to-fuel ratio in operation, monitoring and prevention of air contamination, process sequence definition to mitigate internal escalation of leakages or thermal events".

3.5 Fire extinguishing

3.5.1 A fixed fire-extinguishing system is required for fuel cell spaces

3.5.2 The fire-extinguishing system is to be suitable for use with the specific primary and reformed fuel and fuel cell technology proposed and included in the risk assessment. IRS may allow any alternative fire safety measures if the equivalence of the measure is demonstrated by a risk assessment considering the characteristics of fuels being used, subject to approval of the flag Administration.

3.5.3 Spaces such as fuel cell, fuel containment, fuel preparation room, bunkering station, etc., are to be fitted with a suitable fixed fire-extinguishing system recommended by the manufacturer and appropriate to the fuel chemistry used in those spaces.

3.5.4 For methanol/ ethanol fuels, a fixed fire-fighting system of alcohol resistant aqueous film forming foam (ARAFFF) is recommended.

3.5.5 Small hydrogen fires may be extinguished by at least two dry-chemical extinguishers or carbon dioxide extinguishers of 5kg capacity.

3.5.6 Fixed systems may have deluge systems or dry-chemical extinguishing systems.

3.5.7 In general, a hydrogen fire should not be extinguished, unless the hydrogen source has been isolated because of the danger of ignition of a large combustible premixed cloud that could develop from unburnt hydrogen. If possible, system components around a hydrogen flame may be cooled with water to prevent mechanical failure due to decreased strength at elevated temperatures.

3.6 Fire dampers

3.6.1 Air inlet and outlet openings are to be provided with fail safe automatic closing fire dampers which are to be operable from outside the fuel cell space.

3.6.2 Before actuation of the fire extinguishing system the fire dampers are to be closed.

3.7 Personnel Protective Equipment for use of hydrogen as fuel

3.7.1 The following protective equipment may be provided and stored at a readily accessible location outside the fuel space in vessels using hydrogen as fuel:

- (a) At least two sets of hydrogen protective clothing including refrigerant gas mask, eye protection, helmets, boots and gloves
- (b) Portable hydrogen detection equipment (at least two sets)
- (c) Two or more power driven air compressors to charge the breathing apparatus.

Section 4

Electrical Installations

4.1 General

4.1.1 In general, the electrical requirements specified in this Section are supplementary/ additional to those specified in the *IRS Rules and Regulations for the Construction and Classification of Steel Ships*.

4.1.2 Electrical equipment are not to be installed in hazardous areas unless essential for operational purposes or safety enhancement.

4.1.3 Where electrical equipment including components of fuel cell systems is installed in hazardous areas it is to be selected, installed and maintained in accordance with standards at least equivalent to 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.

4.1.4 Means are to be provided for protection of the fuel cell installation against short circuits and flow of reverse current.

4.1.5 Hoses, transfer arms, piping and fittings provided by the delivering facility used for bunkering are to be electrically continuous, suitably insulated and are to provide a level of safety compliant with recognized standards.

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. In cases where the prescriptive provisions in 4.2.2 are deemed to be inappropriate, area classification according to IEC 60079-10:2020 may be applied with special consideration by IRS and/ or the Administration.

4.2.2 Definition of zones

4.2.2.1 Hazardous areas zone 0

.1 The interiors of buffer tanks, reformers, pipes and equipment containing low-flashpoint fuel or reformed fuel, any pipework of pressure-relief or other venting.

4.2.2.2 Hazardous areas zone 1

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

.2 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 reformed fuel are located.

.5 Fuel cell spaces.

4.2.2.3 Hazardous areas 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

4.2.3 Ventilation ducts are to have the same area classification as the ventilated space.

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

4.2.5 The risks are to be analyzed 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, short-term power failure (blackout) are to, as a minimum be considered. The analysis is to ensure that risks are eliminated wherever possible. Risks which cannot be eliminated are to be mitigated as necessary.

4.3 Certified safe Equipment

4.3.1 Certified safe equipment is equipment intended for installation in hazardous areas where flammable or explosive gases, vapors, or dust are normally or likely to be present. The equipment is to be type-tested and certified by a competent, independent testing laboratory for complying with IEC Publication 60079 series or other recognized standard, and rated according to its enclosure and the types of flammable atmosphere in which it is safe to install.

4.3.2 Certified safe equipment is to be rated for the flammable atmosphere in which it is safe to install. Each flammable atmosphere is to be identified with respect to the flammable gas, vapour or dust and its auto-ignition temperature; the latter being used to limit the maximum permissible external surface temperature of the equipment. The following tables show the typical flammable gas groups and the temperature classes as indicated in IEC 60079:

| S.No. | Gas | Gas Group | Temperature Class |
|--------------|-----------------------|------------------|--------------------------|
| 1 | Methane (Natural Gas) | II A | T1 |
| 2 | Propane, Butane | II A | T2 |
| 3 | Methanol | II A | T2 |
| 4 | Ethanol | II B | T2 |
| 5 | Hydrogen | II C | T1 |

4.3.3 Essential equipment required for safety are not to be de-energized and are to be of a certified safe type. This may include lighting, fire detection, public address and general alarms systems.

4.4 Emergency Shutdown

4.4.1 In general, arrangements are to be provided for the disconnection or shutdown, either selectively or simultaneously, of all electrical equipment and devices, including the emergency generator, except for the services listed in accordance with the applicable sections of the Rules, from the emergency control stations (see Cl. 4.4.4). Initiation of the above shut-downs may vary according to the nature of the emergency. A recommended shut down sequence is to be provided in the vessel's operating manual.

4.4.2 To address risks associated with technical faults and inadvertent operations of the emergency shutdown, each vessel is to develop a detailed plan for recovery and restoration of operation after operation of each level of ESD.

4.4.3 If limit values determined for the control process, e.g. temperature, pressure, or voltage, which may lead to hazardous situations, the fuel cell power system are to be automatically shut down and interlocked by an independent protective device.

4.4.4 Manual Emergency Shutdown

.1 The means of manual emergency shutdown of fuel cell power system is to be provided the following locations as fitted:

- a) Navigating bridge
- b) Continuously manned central control station
- c) Engine control room
- c) Fire control station
- d) Adjacent to the exit of the fuel cell space

Section 5

Control, Monitoring and Safety Systems

5.1 General

5.1.1 Safety related parts of the fuel cell control systems are to be designed independent from any other control and monitoring systems or are to comply with the process as described in recognised standards such as EN ISO 13849-1:2016-06 for the performance level.

5.1.2 The overall system design is to be based on single-fault criteria. The system is to be designed such that a single fault of a component will not lead to serious consequences.

5.1.3 Suitable instrumentation devices are to be fitted to allow a local and a remote reading of essential parameters to provide safe management of the whole fuel-gas system including bunkering.

5.1.4 At least one bilge well with a level indicator is to be provided for each enclosed space where an independent storage tank without a protective cofferdam or secondary barrier is located. Alarms are to be given at a high level in the bilge well. The leakage detection system is to trigger an alarm and safety functions in accordance with Table 5.12.

5.1.5 For tanks not permanently installed in the ship, a monitoring system is to be provided that is equivalent for the permanently installed tanks. Liquid leakage detection is to be installed in the protective cofferdams or secondary barrier space surrounding the fuel tanks, in all ducts around fuel pipes, in fuel preparation rooms, and in other enclosed spaces containing single walled fuel piping or other fuel equipment.

5.1.6 Chemical reactions, such as those that occur during fuel reforming or within the fuel cell, are to be monitored (e.g., by means of temperature, pressure or voltage monitoring).

5.1.7 If limit values determined for the process (e.g., temperature, pressure, voltage) which may lead to hazardous situations are exceeded, the fuel cell power system is to be automatically shut down and interlocked by an independent protective device

5.1.8 Computer based systems where used for control, monitoring and safety systems are to comply with the applicable provisions of Part 4, Chapter 7, Section 6 of the *IRS Rules and Regulations for the Construction and Classification of Steel Ships*.

5.2 Gas or vapour detection

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

- .1 fuel cell spaces (containing fuel piping, fuel equipment or consumers);
- .2 air locks (if any);
- .3 all ventilated spaces of the double walled fuel pipes;
- .4 fuel preparation rooms;
- .5 cofferdams surrounding fuel tanks

.6 at ventilation inlets to accommodation spaces, if required based on the risk assessment.

.7 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

.8 other enclosed spaces where primary/reformed fuel may accumulate.

5.2.2 The detection systems are to continuously monitor for gas/vapour. The number of detectors in the fuel cell space are to be considered taking size, layout and ventilation of the space into account. Gas dispersal analysis or a physical smoke test is to 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.

5.2.4 The vapour detection required is to be continuous and without delay.

5.3 Liquid detection

5.3.1 Arrangement is to be provided to rapidly detect leakages of liquid primary fuel inside the fuel cell space.

5.4 Ventilation performance

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

5.5 Bilge wells

5.5.1 Bilge wells in fuel cell spaces are to be provided with level sensors.

5.6 Bunkering and Fuel Tank Monitoring

5.6.1 The following requirements are applicable to any fuel (liquid or vapour state). The gauging devices are to be selected appropriately:

.1 Level indicators for fuel tanks

(i) Each fuel tank is to be fitted with approved level gauging devices, arranged to provide a level reading whenever the fuel tank is operational. The devices are to be designed to operate throughout the design pressure range of the fuel tank and at temperatures within the fuel operating temperature range.

(ii) Unless necessary maintenance can be carried out while the fuel tank is in service, two level gauging devices are to be installed.

.2 Overflow control

(i) Each fuel tank is to be fitted with a visual and audible high level alarm. These are to be able to be function tested from outside the tank and can be common with the level gauging system, but are to be independent of the high-high level alarm.

(ii) An additional sensor (high-high level) operating independently of the high liquid level alarm is to automatically actuate a shutoff valve in a manner that will both avoid excessive liquid pressure in the bunkering line, and prevent the fuel tank from becoming liquid full.

(iii) The high and high-high level alarm for the fuel tanks are to be visual and audible at the location at which gas-freeing by water filling of the fuel tanks is controlled, given that water filling is the preferred method for gas-freeing

5.7 Fuel Pump Monitoring

5.7.1 Fuel pumps are to be fitted with audible and visual alarms the following locations:

- (i) Navigation bridge
- (ii) Engine control room
- (iii) Fuel preparation room

5.7.2 As a minimum, the alarms are to indicate the following:

- (i) low fuel input pressure
- (ii) low fuel output pressure
- (iii) high fuel output pressure
- (iv) fuel pump non-operation

Note: Additional alarms and indications may be required based on risk assessment.

5.8 Fuel cell condition monitoring

5.8.1 All operating conditions are to be monitored to verify they are within the acceptable design range specified by the manufacturer.

5.8.2 A failure mode and effect analysis examining all possible faults affecting the fuel cell operation and safety are to be carried out. Based on the outcome of the analysis, the extent of the monitoring and control are to be decided. As a minimum the following items are to typically be monitored, as applicable:

- (i) Cell voltage
- (ii) Cell voltage deviations
- (iii) Exhaust gas temperature
- (iv) Fuel cell temperature
- (v) Electric current

5.8.3 Other typical monitoring that could be considered depending upon the fuel cell technology, are as follows:

- (i) Air flow

-
- (ii) Air pressure
 - (iii) Cooling medium flow, pressure, temperature (if applicable)
 - (iv) Fuel flow
 - (v) Fuel temperature
 - (vi) Fuel pressure
 - (vii) Gas detection based on the risk assessment
 - (viii) Water system level
 - (ix) Water system pressure
 - (x) Water system purity
 - (xi) Parameters necessary to monitor lifetime/ deterioration.

5.8.4 The fuel cell power system is to be arranged for manual remote emergency stop from the following locations:

- (i) Cargo control room (as relevant)
- (ii) Navigation bridge
- (iii) Engine control room
- (iv) Fire control station

5.8.5 The fuel cell operation condition indicators (see 5.8.2 & 5.8.3) are to be fitted on the navigation bridge and the engine control room, as appropriate.

5.9 Fuel supply remote emergency stop

5.9.1 Fuel supply is to be arranged for manual remote emergency stop from the following locations as applicable:

- (i) navigation bridge;
- (ii) cargo control room (as relevant);
- (iii) engine control room;
- (iv) fire control station; and
- (v) adjacent to the exit of the fuel cell space

5.10 Emergency shutdown push buttons

5.10.1 Emergency shutdown push buttons are to be provided inside or close to a fuel cell space, in the engine control room and on the navigation bridge. The activation device is to be arranged as a physical button, duly marked and protected against inadvertent operation. The emergency shutdown is to be handled by the safety system and be arranged with loop monitoring.

5.11 Actions of the alarm system and safety system

5.11.1 Gas or vapour detection

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

.2 Gas/ vapour detection in a fuel cell space above a gas or vapour concentration of 40% LEL is to shut-down the affected fuel cell power system and disconnect ignition sources and is to result in automatic closing of all valves required to isolate the leakage. Valves in the primary fuel system supplying liquid or gaseous fuel to the fuel cell space are to close automatically.

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

.4 Gas/vapour detection is to be provided in the at the process air outlet exhaust, and this is to initiate an automatic shutdown and isolation of hydrogen supply.

.5 Gas/vapour detection is to be provided in the inter-barrier spaces

5.11.2 Liquid detection

.1 Detection of liquids is to interrupt the fuel supply to the fuel cell space and de-energize the ignition sources inside the fuel cell space.

5.11.3 Loss of ventilation

.1 Any loss of the required ventilating capacity is to be give an audible and visual alarm on the navigation bridge, in a continuously manned central control station or fire control station, as well as locally.

.2 Loss of ventilation in a fuel cell space is to 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 is to be considered on a case by case basis based on the risk analysis.

.3 After the period has expired, a safety shut down is to be carried out.

5.11.4 High liquid level in bilge wells

.1 Alarm is to be activated at high liquid levels in bilge wells.

5.11.5 Emergency shutdown push buttons

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

5.11.6 Loss of fuel cell coolant

.1 Loss of fuel cell coolant is to 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 enclosure, a secondary containment of the coolant pipe is to be provided or the equipment within the fuel cell enclosure is to be protected from a coolant release. Consideration is to be given to the safe removal of the coolant.

5.11.7 Fire detection

.1 Fire detection is to initiate automatic shutdown and isolation of the fuel supply within the FCS.

5.11.8 Alarm, Monitoring and Safety Actions

.1 The requirements above and Table 5.11 below specify recommended alarms and safety actions for fuel cell power installations to limit the consequences of system failures.

.2 Alarms and safety actions additional to the ones required by the Table may be recommended for unconventional or complex fuel cell power installations, based on the risk assessment carried out.

| Parameter | Alarm | Automatic Shutdown of fuel space valve/ tank valve | Automatic Shutdown of ignition source/ master fuel valve | Automatic shutdown of bunkering valve | Remarks |
|---|-------|--|--|---------------------------------------|---|
| High Level Fuel Tank | X | | | X | See 5.6.1 |
| High, High Level Fuel Tank | X | | | X | See 5.6.1 |
| Loss of ventilation in annular space in bunkering line | X | | | X | See 2.11.1 |
| Gas detection in annular space in bunkering line | X | | | X | See 2.11.1 |
| Loss of ventilation in ventilated areas | X | | | | See 5.11.3 |
| Loss of ventilation or negative pressure in fuel cell space | X | X | | | The fuel cell is to be automatically shut down by process control, See 5.11.3 |
| Gas detection in cofferdams surrounding fuel tanks. One detector giving 20% of LEL | X | | | | See 5.2.1 |
| Gas detection in cofferdams surrounding fuel tanks. Two detectors giving 40% of LEL | X | X | | X | See 5.2.1 |
| Gas detection in fuel cell spaces/ other areas | X | | | | See 2.3.2 & 5.2.1 |

| | | | | | |
|--|---|---|---|---|---|
| Gas detection in ducts around double walled pipes. One detector giving 20% of LEL | X | | | | See 2.11.10 & 5.2.1 |
| Gas detection in ducts around double walled pipes. Two detectors giving 40% of LEL | X | X | X | | See 2.11.10 & 5.2.1 |
| Gas detection in fuel cell spaces. Two detectors giving 40% of LEL | X | X | | X | See 2.3.2 & 5.2.1 |
| Liquid leak detection in annular space of double walled pipes | X | X | X | | See 2.11.10 |
| Liquid leak detection in fuel cell space | X | X | X | | See 5.1.5 |
| Liquid leak detection in machinery space | X | X | | | |
| Liquid leak detection in pump room | X | X | | | |
| Liquid leakage detection in protective cofferdams surrounding fuel tanks | X | | | | See 5.1.5 |
| High Liquid level in bilge wells of fuel cell spaces | X | | | | See 5.1.5 |
| Expansion tanks/degassing vessels in systems for heating/cooling | X | | | | |
| Air Locks | X | | | | See 5.2.1 |
| Other spaces where primary/ reformed fuel may accumulate | X | | | | See 5.2.1 |
| Fire Detection | X | X | X | X | Shutdown of ventilation, release of fire extinguishing system |
| Emergency Shutdown | X | X | X | X | See 5.11.5, 5.11.6 |
| <p><u>Note:</u> The risk assessment is to include any other necessary parameters, based on the fuel and fuel cell technology used, for the safe and effective operation of the control monitoring and safety system.</p> | | | | | |

Section 6

Inspection and Maintenance

6.1 General

6.1.1 The procedures and information are to include maintenance of electrical equipment that is installed in explosion hazardous spaces and areas. The inspection and maintenance of electrical installations in explosion hazardous spaces are to be performed in accordance with a recognized standard. (e.g., IEC 60092-502 and IEC 60079-17).

6.1.2 An inspection and maintenance manual is to be prepared for electrical equipment that is installed in explosion hazardous spaces and areas in accordance with IEC 60092-502.

6.2 Inspection and Maintenance Manual

6.2.1 The inspection and maintenance manual is to include, but not be limited to the following:

- (i) Hazardous area classification and, if included, the equipment protection level required for each location
- (ii) Equipment characteristics (e.g., temperature ratings, type of protection, IP rating, corrosion resistance)
- (iii) Records sufficient to enable the explosion protected equipment be maintained in accordance with its type of protection
- (iv) Copies of initial and previous inspection records
- (v) All electrical equipment located in hazardous areas and in the spaces which may become hazardous on loss of pressurization are to be, together with any associated safe-area apparatus required for the protection of the equipment, listed on a maintenance schedule. The schedule is to include the following details:
 - Location
 - Zonal classification of location
 - Type of equipment
 - Manufacturer
 - Type reference
 - Test authority and certificate number, or, reference and date of manufacturer's declaration
 - Type of protection
 - Apparatus group
 - Temperature class
 - Ambient temperature range for which equipment is suitable
 - Ingress protection (IP) rating

6.3 Personnel Qualification and Training

6.3.1 The necessary basic training for the inspection and maintenance of installations covered by these Guidelines are to be carried out only by experienced personnel.

6.3.2 All personnel involved with the use of hydrogen should be trained in the knowledge of the physical, chemical and hazardous properties of hydrogen pertaining to the applications with which they are involved. Training should include actions to be taken in the event of an emergency, such as unignited release, fire, detonation. Training should also include first aid procedures for emergency care of injuries, including those for cold and cryogenic injuries.

6.3.3 Documentation verifying compliance with 6.3 is to be made available to the Surveyor on request.

Section 7

Surveys

7.1 General

7.1.1 The fuel cell power installations are to be maintained in satisfactory condition. The survey requirements indicated in this Section are intended for vessels fitted with fuel cell installations. Other surveys are to be carried as relevant and applicable, in accordance with the Rules.

7.1.2 The manufacturer is to provide the information necessary for safe installation, operation, and servicing of the fuel cell power system and is in particular to draw attention to any restrictions on use. The information is to be provided in the form of technical documents such as drawings, diagrams, instructions, and these are to be on suitable data medium and language. The installation manual is to provide the installer with all the information necessary for setting-up of the fuel cell power system.

7.2 Surveys during Construction

7.2.1 Surveys during construction would consist of the following, as relevant and applicable:

- (a) Surveys at Manufacturers Works
- (b) Initial Surveys including testing and trials

7.2.2 Surveys at Manufacturer's Works

.1 Table 1.7.1 of these guidelines specify the certification requirements of fuel cells and associated systems. Equipment manufactured and packed at manufacturer's works would be subject to surveys as summarized.

.2 The fuel cell power system should be marked and provided with a data plate. Marking and mounting are to be durable and suitable for the application.

.3 The data plate/label is to include the following information:

- (a) Manufacturer's name (with trademark), and location
- (b) Manufacturer's model number or trade name
- (c) Serial number of the fuel cell power system and year of manufacture
- (d) Electrical input, as applicable (voltage/type of current/frequency/phase/power/consumption)
- (e) Electrical output (voltage/type of current/frequency/phase /rated power/power factor; kVA)
- (f) Fuel type to be used by the fuel cell power system
- (g) Range of fuel supply pressure
- (h) Fuel consumption at rated power (kW)
- (i) Range of ambient temperatures (minimum and maximum) within which the fuel cell power system is intended to operate (in degrees Celsius)
- (j) Suitable location for use: indoor or outdoor
- (k) Warnings for alerting personnel to the potential for personal injury or equipment damage and requirements to follow installation and operation instructions.

.4 All user serviceable parts are to be identified to match the fuel cell power system drawings in the user manual.

7.2.3 Initial Surveys

.1 A testing and trial protocol is to be submitted to IRS for approval. The protocol is to identify all equipment and systems, listing performance tests or trials, as relevant and applicable.

.2 A survey plan for the fuel containment system is to be submitted to IRS for approval. The survey plan is to identify components/systems to be examined and/or verified during surveys throughout the fuel containment system's life and, in particular, any necessary in-service inspections, maintenance and testing that was considered when selecting the fuel containment system design parameters .

.3 All certified safe systems and instrumentation and control panels are to be verified to be in compliance with approved drawings.

.4 Non-destructive examination tests and records of non-destructive examinations are to be reviewed, as necessary.

.5 Piping systems are to be visually examined and pressure-tested, as required by the Rules.

.6 Pressure relief and safety valves installed in the systems are to be tested.

.7 Electrical wiring, connections and instrumentation are to be checked and tested in accordance with the requirements of the Rules and these Guidelines.

.8 Onboard testing is to be carried out to verify that correct functionality has been achieved with all systems in operation. All fuel cell and related systems are to be examined and tested to satisfaction of the attending Surveyor in accordance with the approved plans.

.9 During the initial trials, satisfactory operation of the fuel cell power system is to be confirmed, including associated controls, alarms and shutdowns. The tests are to be conducted in accordance with the approved trial protocols.

7.3 Periodical Surveys

7.3.1 Annual Surveys

7.3.1.1 The following are to be carried out, as relevant and applicable:

(i) Confirming that the operation and maintenance manuals relevant to fuel storage, bunkering, fuel supply and associated fuel systems are available on-board.

(ii) Examination of logbooks and records for appropriate functioning of the gas detection, fire detection and alarm system, fuel cell operation hours, etc.

(iii) Confirmation of satisfactory operation (iii) of the gas detection and other leakage detection equipment fitted in various compartments.

(iv) Verification of the satisfactory operation of the control, monitoring and automatic shutdown systems

(v) Operational test, as far as practicable of the ESD arrangements

-
- (vi) Piping, hoses, emergency shut-down valves, remote operating valves, relief valves, machinery and equipment for fuel storage, fuel bunkering, and fuel supply such as venting, compressing, refrigerating, reliquefaction, heating, cooling or otherwise handling the fuel are to be examined, as far as practicable.
 - (vii) Means for inerting is to be examined. Stopping of pumps and compressors upon emergency shutdown of the system is to be verified as far as practicable.
 - (viii) General examination of the ventilation system in various compartments, and operational testing of the alarms, as far as practicable.
 - (ix) Examination of portable and fixed drip trays
 - (x) Electrical equipment and bulkhead/deck penetrations including access openings in hazardous areas are to be examined for continued suitability for their intended service.
 - (xi) Examination of fire-fighting equipment and operational testing, as far as practicable.
 - (xii) Electrical bonding arrangements in hazardous areas, including bonding straps where fitted, are to be examined.
 - (xiii) General examination of the fuel supply, storage and bunkering system, as far as practicable.
 - (xiv) Verification of the satisfactory operation of the fuel bunkering and fuel supply control, monitoring and shutdown systems.

7.3.2 Special Surveys

7.3.2.1 In addition to the requirements of the annual surveys, the following are to be carried out:

- (i) All piping for fuel storage, fuel bunkering, and fuel supply such as venting, compressing, refrigerating, liquefying, heating storing, burning or otherwise handling the fuel and liquid nitrogen installations are to be examined. Removal of insulation from the piping and opening for examination may be required. Suspect areas of the pipeline may be subjected to hydrostatic tests. After assembly, the complete pipeline is to be leak tested.
- (ii) Fuel valves are to be randomly selected and opened for examination.
- (iii) All PRVs in fuel storage tanks, fuel supply and bunkering piping, and in hold spaces; are to be opened for examination, adjusted and function tested.
- (iv) Examination of electrical equipment to include the physical condition of electrical cables and supports, intrinsically safe, explosion proof, or increased safety features of electrical equipment.
- (v) Functional testing of pressurized equipment and associated alarms.
- (vi) Testing of systems for de-energizing electrical equipment which is not certified for use in hazardous areas.

(vii) An electrical insulation resistance test of the circuits terminating in, or passing through, the hazardous zones and spaces is to be carried out.

(viii) Gas detectors, temperature sensors, pressure sensors, level indicators, and other equipment providing input to the fuel safety system are to be tested to confirm satisfactory operating condition. The sensors are to be re-calibrated in accordance with manufacturer's instructions.

(ix) Fuel storage tanks are to be examined in accordance with an approved testing plan and relevant requirements of the Rules.

Appendix A

Fuel Cell Technologies

1. A fuel cell is a device for directly converting the chemical energy of a fuel, such as hydrogen or a hydrogen-rich gas, and an oxidant into electrical energy. Fuel cell systems are composed of three basic elements, the heart of which is the fuel cell itself (Fig. 1). The fuel supply subsystem, usually a processor for producing hydrogen gas, and an electrical converter, for providing electrical power in a form acceptable to the user, make up the two other elements. A typical fuel cell power installation is shown in Fig.2.

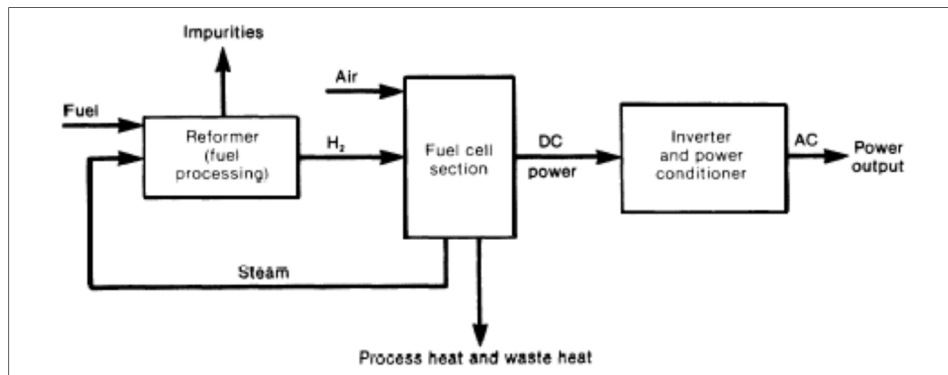


Fig. 1 Diagram of major components of a fuel cell

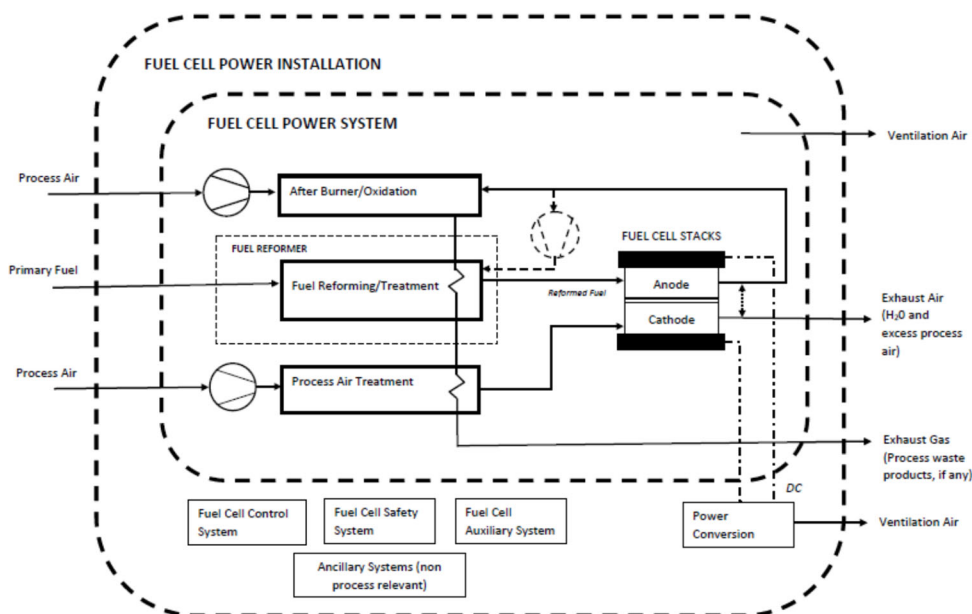


Fig.2 Typical Fuel Cell Power Installation

2. Fuel cell characteristics and performance typically vary depending on the materials used for electrodes, electrolytes and catalysts. A brief description of the most commonly used fuel cell technologies is given below. Comparison between the various fuel technologies is provided in Table 1:

(a) The alkaline fuel cell (**AFC**) consists normally of a nickel anode, a silver cathode and an alkaline electrolyte. The electrolyte is an alkaline solution (eg. potassium hydroxide, KOH) which can be either mobilized or immobilized in a matrix. The fuel is hydrogen (H₂) and oxygen (O₂) and hydroxyl ions (OH⁻) are transported through the electrolyte from the cathode to the anode. The hydrogen and oxygen needs to be pure to avoid degradation of the AFC.

(b) The polymer electrolyte membrane or proton exchange membrane fuel cell (**PEMFC**) uses platinum-based electrodes and the electrolyte is a humidified polymer membrane that is an electric insulator, but permeates hydrogen ions (H⁺). The operating temperature is 50-100°C, temperatures above 100°C is not feasible as the membrane needs to stay humid. The PEMFC uses hydrogen and oxygen, and produces water in addition to electricity and heat. If other fuel sources than hydrogen is to be used it needs to be converted to hydrogen prior to injection to the PEMFC. For hydrocarbons this means steam reforming and water-gas-shift.

(c) Phosphoric acid fuel cell (**PAFC**) is a fuel cell with higher temperature, operating at temperatures up to 200°C. The increased temperature means that the excess heat from the fuel cell is of such a quality that it can be utilised, increasing the overall efficiency of the fuel cell. PAFC has an electrolyte of phosphoric acid in a silicon carbide structure and electrodes made of platinum dispersed on carbon. The PAFC uses hydrogen as fuel under acidic conditions, the reactions that occur is therefore the same as in PEM fuel cells. Due to the higher temperatures, other fuel sources than pure hydrogen can be used. This includes hydrocarbons like LNG and methanol.

(d) The molten carbonate fuel cell (**MCFC**) is a high temperature fuel cell operating at temperatures between 600-700°C. The electrolyte is a molten carbonate salt, and there is no need for noble-metal catalyst. The anode is normally a nickel alloy and the cathode is normally nickel oxide with lithium incorporated in the structure. The high temperature makes the MCFC flexible towards the choice of fuel, both LNG, flue gases from coal and hydrogen can be used. A reforming unit is not needed, as the reforming occurs in the fuel cell itself.

(e) Solid oxide fuel cells (**SOFC**) is another high temperature fuel cell. The SOFC operates at temperatures between 500-1000°C. The electrolyte is a porous ceramic material, yttrium stabilized zirconia is common. Similar to the MCFC, the SOFC uses a nickel alloy as the anode, but the cathode is normally made of lanthanum strontium manganite, a material that has the required porosity and is compatible with the electrolyte.

Table 1 : Comparison of Fuel Cell Technologies

| Fuel Cell Type | Alkaline Fuel Cell (AFC) | Polymer Electrolyte Membrane Fuel Cell (PEMFC) | Phosphoric Acid Fuel Cell (PAFC) | Molten Carbonate Fuel Cell (MCFC) | Solid Oxide Fuel Cell (SOFC) |
|-----------------------|--|---|---|--|--|
| Anode | Platinum or Carbon | Platinum | Platinum | Steel/nickel | Ceramic |
| Electrolyte | Potassium Hydroxide (KOH) | Polymer Membrane | Phosphoric Acid (H ₃ PO ₄) | Molten Carbonate | Yttria-Stabilized Zirconia (YSZ) |
| Electrolyte | Liquid | Solid | Liquid | Solid | Solid |
| Fuel | Hydrogen, Ammonia | Hydrogen | Hydrogen, Methanol | Natural gas, Methanol, Ethanol, Biogas, Coal gas | Natural gas, Methanol, Ethanol, Biogas, Coal gas |
| Operating Temperature | < 100°C | < 120°C | 150-200 °C | 600-700 °C | 500-1000 °C |
| Typical stack size | 1-100 kW | < 1kW – 100kW | 5 - 400 kW | 300 kW – 3 MW | 1 kW – 2 MW |
| Efficiency | 60% | 60% direct H ₂ 40% reformed fuel | 40% | 50% | 60% |
| Advantages | <ul style="list-style-type: none"> • Wider range of stable materials allows lower cost components • Low temperatures • Quick startup | <ul style="list-style-type: none"> • Solid electrolyte reduces corrosion and electrolyte management problems • Low temperatures • Quick startup and load following | <ul style="list-style-type: none"> • Suitable for Combined Heat and Power (CHP) • Increased tolerance to fuel impurities | <ul style="list-style-type: none"> • High Efficiency • Fuel Flexibility • Suitable for CHP • Hybrid/ Gas Turbine cycle | <ul style="list-style-type: none"> • High Efficiency • Fuel Flexibility • Solid Electrolyte • Suitable for CHP • Hybrid/ Gas Turbine cycle |
| Challenges | <ul style="list-style-type: none"> • Sensitive to CO₂ in fuel and air • Electrolyte Management • Electrolyte Conductivity • Liquid catalyst adds weight • Relatively large | <ul style="list-style-type: none"> • Expensive catalysts • Sensitive to fuel impurities such as Sulphur and CO • Sensitive to humidity • Sensitive to salinity • Sensitive to low temperatures | <ul style="list-style-type: none"> • Expensive catalysts • Sulphur Sensitivity • Long Start-up Time • Less powerful | <ul style="list-style-type: none"> • High temperature corrosion and breakdown of cell components • Long Start-up time • Low power density • Highly corrosive | <ul style="list-style-type: none"> • High temperature corrosion and breakdown of cell components • Long Start-up time • Limited number of shutdowns • Intense heat |

Appendix B

Risks associated with Hydrogen as fuel in fuel cells and possible mitigation measures

In general, this Appendix gives guidance on hazards and risk mitigation measures based on use of hydrogen as a fuel. However, a detailed risk assessment of the vessel design is to be carried out in order to address risk associated with specific applications.

1. Hazards associated with Hydrogen

1.1 Fire/Explosion

1.1.1 Hydrogen for use in fuel cells may be stored in a number of ways:

- As a compressed gas -normally in conventional gas cylinders at a pressure of 200bar, but this pressure may be increased in specialist applications to increase energy storage density.
- As a cryogenic liquid -hydrogen is stored as a liquid below -250°C therefore, consideration should be given to cold burns, condensation of oxygen-enriched atmospheres, and the way in which a liquid spill may develop into a flammable cloud. It should be appreciated that the vapour produced by a liquid spill will not initially be buoyant due to its low temperature.
- Complex hydrides are also used as a hydrogen storage medium, generally based on sodium aluminium hydrides or similar materials. These materials are flammable solids and can react violently with water to produce hydrogen and a corrosive aqueous solution. Hydride storage systems can be suitably designed to avoid these hazards.

1.2 Leakage

1.1.2 Hydrogen gas has a very low viscosity and so it is very difficult to prevent hydrogen systems from developing leaks. Pipe work that was 'leak tight' when pressure-tested with nitrogen will often be found to leak profusely when used on hydrogen duty.

1.2.2 Hydrogen is stored at high pressures or cryogenic temperatures, and because the hydrogen molecule is so small, hydrogen is more leak prone than other fuels.

1.2.3 Hydrogen leakage through welds, flanges, seals, gaskets, etc is an important consideration and an important design and operational issue for hydrogen systems.

1.2.4 The use of suitable sealing interfaces and appropriate components within a hydrogen system, however, will significantly reduce the likelihood of this occurring if fitted by a competent person. For high-pressure storage systems, hydrogen would leak nearly three times faster than natural gas and over five times faster than propane. However the low energy density of hydrogen means that it produces substantially lower energy leakage rates.

1.2.5 While Hydrogen's low M.W. makes it more leak-prone, its exceptionally high sound speed and low viscosity cause hydrogen leaks through a given size opening to have a much higher velocity and volumetric flow rate relative to other gaseous or liquid fuels.

1.3 High diffusivity

1.3.1 Hydrogen is very much lighter than air and is also very diffusive. Thus, unlike heavier gaseous fuels, if a hydrogen leak occurs in an open or well-ventilated area its diffusivity and buoyancy will help to reduce the likelihood of a flammable mixture forming in the vicinity of the leak.

1.3.2 However, as with other gases when leaks occur within poorly ventilated or enclosed areas, the concentration may rapidly reach dangerous levels. Due to its lightness, hydrogen will concentrate in elevated regions of an enclosed space, whereas other gases, dependent upon their relative mass, will concentrate at ground level (LPG) or at elevation (CNG). If unprotected electrical equipment or other sources of ignition are present, the risk from explosion could be considerable.

1.3.3 As hydrogen diffuses more rapidly through air and through solid materials compared to other fuel gases such as methane or propane, it will usually disperse more rapidly if released, although buoyancy effects are less significant for high momentum releases from high-pressure hydrogen systems. When harnessed through intelligent equipment design and layout, this buoyancy and hydrogen's rapid dispersion rate can become a significant safety asset.

1.4 High buoyancy

1.4.1 Hydrogen gas is highly buoyant. Because of its extraordinary buoyancy has substantial safety implications. Hydrogen rises very rapidly. Even when considering hydrogen's high diffusion coefficient, hydrogen plumes do not spread horizontally very far before the conc. decreases below LFL. This is because the vertical movement and mixing is so rapid. Because of hydrogen's buoyancy makes it a relatively safe fuel. However, hydrogen leaks inside enclosed spaces with overhead ignition sources are dangerous.

1.4.2 The buoyancy of hydrogen can also be used to manage the risk normally associated with fuel handling by segregating the hydrogen from foreseeable sources of ignition using internal partitions and bulkheads and differential pressurization. This can also be done by locating all potential sources of ignition well below the level of the equipment from which hydrogen may leak and accumulate, and ensuring adequate ventilation and safe discharge of the exhaust.

1.5 Propensity to cause embrittlement

1.5.1 Hydrogen can cause embrittlement of high strength steels, titanium alloys and aluminium alloys with cracking and catastrophic failure of the metals at stress below the yield stress. This is most commonly related to the carbon content of metallic alloys. Pure, unalloyed aluminium, however, is highly resistant to embrittlement. The industry standard for components in hydrogen service is grade 316 stainless steel. Cupro-nickel is also suitable for hydrogen service and copper can be used for low-pressure applications.

1.6 Wide flammability range

1.6.1 Hydrogen readily forms an explosive mixture with air. The range of hydrogen/air mixtures that will explode is wide. Mixtures containing from as little as 4% v/v hydrogen, which is the lower explosive limit (LEL), up to as much as 75% v/v, which is the upper explosive limit (UEL), may propagate a flame. The wide range of flammability of hydrogen-air mixtures compared to propane and methane-air mixtures is, in principle, a disadvantage. There are, however, only minor differences between the LEL of hydrogen and that of methane or propane. The LEL of hydrogen is considered by many experts to have a greater significance in hazard ranking than the width of the fuel's flammable range. Furthermore, in the case of low momentum releases, the dispersion characteristics of hydrogen will make it less likely that a flammable mixture will form.

1.7 Very low ignition energy

1.7.1 The energy necessary to initiate a hydrogen/air explosion is very small. The ignition energy for a 2:1 hydrogen/oxygen mixture is only about 0.02 mJ. This is less than one tenth that of other fuels such as methane, LPG or petrol. Even very small sparks, such as those produced by wearing certain types of clothing, are capable of igniting hydrogen/air mixtures and causing an explosion.

1.8 Spontaneous ignition

1.8.1 Hydrogen has the possibility to spontaneously ignite on sudden release from pressurized containers.

1.9 Invisible flame

1.9.1 Hydrogen burns with an invisible flame making it difficult to detect a hydrogen fire. This apparent low emissivity of hydrogen flames (total heat flux radiated) may reduce the heat transfer by radiation to objects near the flame, thus reducing the risks of secondary ignition and burns.

1.10 Rapid burning rate/Burning velocity

1.10.1 The maximum burning velocity of a hydrogen-air mixture is about eight times greater than those for natural gas and propane air mixtures. The high burning velocity of hydrogen makes it difficult to confine or arrest hydrogen flames and explosions, particularly in closed environments. In its favour, however, this rapid rate of deflagration means that hydrogen fires transfer less heat to the surroundings than other gaseous fuel fires, thereby reducing the risk of creating secondary fires in neighbouring materials. Another downside of a higher burning velocity of hydrogen is that for a given scenario hydrogen would result in higher explosion pressures and rates of pressure rise than other fuels.

1.11 Possibility of detonation

1.11.1 Hydrogen/air mixtures have a greater propensity to detonate than mixtures of air with other more common flammable fuels. Detonations cause much more damage and are far more dangerous than ordinary explosions (deflagrations). However, due to the rapid dispersal characteristics of hydrogen, this is only likely to occur in a confined or congested space.

1.12 Detectability

1.12.1 While hydrogen is relatively leak prone, hydrogen leaks and flames are both difficult to detect. Hydrogen, methane and propane are essentially odourless. Odorants, typically mercaptans, are often added to natural gas and LPG so that leaks can be detected by their smell. However, it is impractical to odorize hydrogen with these compounds because even very small sulphur conc. found in these odorants poison fuel cells.

1.13 Quenching Distance:

1.13.1 Flame arrestors, which stop flames from propagating, are used on components such as vent stack and electrical enclosures. At 1 atm, the quenching distance is about 0.06 cm for hydrogen compared to 0.2 cm for propane.

2. Based on the above, the following hazards need to be mitigated for hydrogen applications:

2.1 Mechanical hazards: The following should be addressed against mechanical hazards

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- Risk of loss of stability;
 - Risks due to falling or ejected objects;
 - Risks due to surfaces, edges or angles;
 - Risks related to variations in operating conditions;
 - Risks related to moving parts;
 - Risks arising from moving parts.

2.2 Electrical hazards : The following should be addressed against electrical hazards:

- Protection against hazards arising from the electrical equipment;
- Protection against hazards which may be caused by external influences on the electrical equipment;
- Electricity supply;
- Static electricity;
- Electromagnetic compatibility.

2.3 Pressure related hazards: The following should be addressed against pressure related hazards:

- Strength of equipment;
- Provisions to ensure safe handling and operation;
- Means of examination;
- Means of draining and venting;
- Materials for pressure vessels;
- Wear;
- Assemblies;
- Provisions for filling and discharge;
- Protection against exceeding the allowable limits of pressure equipment;
- Safety accessories;
- Manufacturing procedures.

3. The safety of the fuel cell and H₂ system is based on:

- (i) continuous monitoring for gas leakage and fire,
- (ii) controlled ventilation of potentially H₂-containing spaces,
- (iii) Explosion-proof installation of electrical devices potentially in contact with H₂-containing atmosphere,
- (iv) an intrinsically safe system normal-state,
- (v) passive protection measures such as fire insulation and explosion relief hatches.

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- (vi) The active safety systems, i.e. gas and fire detection, ventilation as well as fire suppression systems are equipped with continuous electronic self-monitoring to ascertain their proper functioning.

3.1 Systems for hydrogen gas safety

- (i) continuous monitoring of hydrogen,
- (ii) automatic shut-off valves,
- (iii) ventilation mechanisms,
- (iv) dedicated relief devices and venting routes to prevent uncontrolled release of gas due to system overpressure,
- (v) Hydrogen detection and alarm system.

3.2 Systems for fire safety

Fire safety is based on active and passive measures including the following:

- (i) continuous fire detection and a related fire alarm system,
- (ii) fire suppression flaps in ventilation channels,
- (iii) fire insulation.

3.3 Other safety systems.

- (i) Emergency stop button for manual emergency stop of system,
- (ii) Explosion relief panels

4 Mitigation measures

4.1 In general, the following mitigation measures may be considered for hydrogen in fuel cell applications:

- (a) Fire protection to the storage tanks
- (b) Pressure reduction by venting (here the rate of venting (maximum acceptable vent rate) is important, which will in turn help to reduce the inventory when required during emergency and thereafter ensure protection of tanks from fire or explosion (external or from other tanks) to maintain integrity until sufficiently depressurized.
- (c) Double wall piping (sensors within the pipes)
- (d) Gas pipe within the ventilation duct (gas sensor in the ventilation channel)
- (e) Gas tight enclosures (e.g gas tight H₂ storage rooms, gas tight fuel cell enclosures etc.)
- (f) Fire safe insulation
- (g) Double block bleed valve configuration
- (h) Hazardous area classification

- (i) Protection of the fuel cells from collision (sufficient distance from shell plating), mechanical damage (protection guards) and fire.
- (j) Thermally activated pressure relief devices (TPRDs) included in the hydrogen storage system to assure a controlled hydrogen release in the case of long-enduring fire.

4.2 Prevention of explosive atmosphere by

- (a) Ventilation
- (b) Two barrier principle
- (c) Prevent accumulation of gas
- (d) Permanently tight systems (e.g. welded pipes)

4.3 Prevention of ignition sources by

- (a) Use of certified equipment
- (b) Temperature below 80% self-ignition temperatures
- (c) Avoiding electrostatic electricity

4.4 Mitigation of Reduction of explosion effects by

- (a) Separation of locations
- (b) Double block bleed valves
- (c) Two barrier principle
- (d) Active (automatic fire suppression/extinguishing system and fire protection insulation) and passive (like melting plugs, safety valves) fire protection measures
- (e) Use of nonflammable materials
- (f) Fuel cell spaces, their arrangement, design and precautions
- (g) Hull materials
- (h) Materials for Piping and systems
- (i) Welding/ Joining of hydrogen piping
- (j) Ventilation/ Atmospheric control, including exhaust etc.
- (k) Fire detection, explosion prevention, fire-fighting
- (l) Area classification/ hazardous zones
- (m) Control Monitoring and Safety Systems

4.4.1 Materials used in gas tanks, gas piping, and process pressure vessels and other components in contact with gas should be in accordance with Part 5 Chapter 4 of the *IRS Rules and Regulations for the Construction and Classification of Steel Ships*.

4.5 Materials selection for installation

4.5.1 Materials used for the installation of hydrogen and fuel cell equipment must be suitable for such application during the scheduled lifetime unless replacement is foreseen.

4.5.2 Where necessary, adequate allowance or protection against corrosion or other chemical attack must be provided, taking due account of the intended and reasonably foreseeable use. Hydrogen gas dissolved in liquids will permeate into adjoining vessel materials. At elevated temperatures and pressures, hydrogen attacks mild steels severely, causing decarburization and embrittlement. It is, therefore, vital that if hydrogen is stored or handled under pressure compatible materials, e.g. special alloy steels, are used for pipe work, vessels, etc.

4.6 Ventilation

4.6.1 Natural or forced (mechanical) ventilation can be used to prevent the formation of potentially explosive mixtures. Natural ventilation is the preferred method due to its intrinsic reliability. If forced ventilation is used, then the reliability of the system has to be considered.

4.6.2 Appliances which are not fitted with devices such as flues to avoid a dangerous accumulation of unburned gas or combustion products in indoor spaces and rooms should be used only in areas where there is sufficient ventilation to avoid accumulation to dangerous levels.

4.7 Pressure systems

4.7.1 Suitable means must be provided for testing and venting pressure equipment. The risk assessment for the installation should cover the pressurizing and venting operations. Adequate means must also be provided to permit cleaning, inspection and maintenance in a safe manner of all pressure systems.

4.8 Fire precautions

4.8.1 Fire precautions are relevant for all aspects of the fuel cell installation, from the hydrogen generation, processing, storage, and piping, to the fuel cells. A fire can often lead to an explosion and, by the same token, an explosion can initiate a fire. It is important, therefore, that a fire and explosion risk assessment be carried out as a single exercise that considers all the fire and explosion hazards that can arise.

4.9 Lightning protection

4.9.1 Lightning protection is to be provided in accordance with the relevant requirements of the Rules.

4.10 Gas venting

4.10.1 In electrolyser-fed systems, venting facilities for hydrogen and oxygen should be separate and isolated from each other.

4.11 Blast walls

4.11.1 Equipment and plant vulnerable to blast damage can be protected by blast walls. These are strong walls positioned between the item to be protected and the expected source of blast that will deflect the blast wave and thus reduce the intensity of explosion pressure experienced.

4.12 Slipping, tripping or falling hazards

4.12.1 Access to the equipment should be such that there are no slipping, tripping or falling hazards for personnel, e.g. gas cylinders, undertaking maintenance or carrying out repairs to the installation.

4.12.2 Rooms or enclosures containing equipment should be fitted with measures to prevent a person from being accidentally trapped within it or, if that is impossible, with a means of summoning help.

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*****End of Guidelines*****