Rules for Fuel Cells Installation in Ships (FC-SHIPS)

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GENERAL CONDITIONS

Definitions:

"*Administration*" means the Government of the State whose flag the Ship is entitled to fly or under whose authority the Ship is authorised to operate in the specific case.

"IACS" means the International Association of Classification Societies.

"*Interested Party*" means the party, other than the Society, having an interest in or responsibility for the Ship, product, plant or system subject to classification or certification (such as the owner of the Ship and his representatives, the ship builder, the engine builder or the supplier of parts to be tested) who requests the Services or on whose behalf the Services are requested.

"*Owner*" means the registered owner, the ship owner, the manager or any other party with the responsibility, legally or contractually, to keep the ship seaworthy or in service, having particular regard to the provisions relating to the maintenance of class laid down in Part A, Chapter 2 of the Rules for the Classification of Ships or in the corresponding rules indicated in the specific Rules.

"Rules" in these General Conditions means the documents below issued by the Society:

(i) Rules for the Classification of Ships or other special units;
(ii) Complementary Rules containing the requirements for product, plant, system and other certification or containing the requirements for the assignment of additional class notations;
(iii) Rules for the application of statutory rules, containing the rules to perform the duties delegated by Administrations;
(iv) Guides to carry out particular activities connected with Services;
(v) Any other technical document, as for example rule variations or interpretations.

"*Services*" means the activities described in Article 1 below, rendered by the Society upon request made by or on behalf of the Interested Party.

"Ship" means ships, boats, craft and other special units, as for example offshore structures, floating units and underwater craft.

"*Society*" or *"TASNEEF"* means Tasneef and/or all the companies in the Tasneef Group which provide the Services.

"*Surveyor*" means technical staff acting on behalf of the Society in performing the Services.

Article 1

1.1. The purpose of the Society is, among others, the classification and certification of ships and the certification of their parts and components. In particular, the Society:
(i) sets forth and develops Rules;
(ii) publishes the Register of Ships;
(iii) issues certificates, statements and reports based on its survey activities.

1.2. The Society also takes part in the implementation of national and international rules and standards as delegated by various Governments.

1.3. The Society carries out technical assistance activities on request and provides special services outside the scope of classification, which are regulated by these general conditions, unless expressly excluded in the particular contract.

Article 2

2.1. The Rules developed by the Society reflect the level of its technical knowledge at the time they are published. Therefore, the Society, although committed also through its research and development services to continuous updating of the Rules, does not guarantee the Rules meet state-of-the-art science and technology at the time of publication or that they meet the Society's or others' subsequent technical developments.

2.2. The Interested Party is required to know the Rules on the basis of which the Services are provided. With particular reference to Classification Services, special attention is to be given to the Rules concerning class suspension, withdrawal and reinstatement. In case of doubt or inaccuracy, the Interested Party is to promptly contact the Society for clarification.
The Rules for Classification of Ships are published on the Society's website: www.tasneef.ae.

2.3. The Society exercises due care and skill:
(i) in the selection of its Surveyors
(ii) in the performance of its Services, taking into account the level of its technical knowledge at the time the Services are performed.

2.4. Surveys conducted by the Society include, but are not limited to, visual inspection and non-destructive testing. Unless otherwise required, surveys are conducted through sampling techniques and do not consist of comprehensive verification or monitoring of the Ship or of the items subject to certification. The surveys and checks made by the Society on board ship do not necessarily require the constant and continuous presence of the Surveyor. The Society may also commission laboratory testing, underwater inspection and other checks carried out by and under the responsibility of qualified service suppliers. Survey practices and procedures are selected by the Society based on its experience and knowledge and according to generally accepted technical standards in the sector.

Article 3

3.1. The class assigned to a Ship, like the reports, statements, certificates or any other document or information issued by the Society, reflects the opinion of the Society concerning compliance, at the time the Service is provided, of the Ship or product subject to certification, with the applicable Rules (given the intended use and within the relevant time frame).
The Society is under no obligation to make statements or provide information about elements or facts which are not part of the specific scope of the Service requested by the Interested Party or on its behalf.

3.2. No report, statement, notation on a plan, review, Certificate of Classification, document or information issued or given as part of the Services provided by the Society shall have any legal effect or implication other than a representation that, on the basis of the checks made by the Society, the Ship, structure, materials, equipment, machinery or any other item covered by such document or information meet the Rules. Any such document is issued solely for the use of the Society, its committees and clients or other duly authorised bodies and for no other purpose. Therefore, the Society cannot be held liable for any act made or document issued by other parties on the basis of the statements or information given by the Society. The validity, application, meaning and interpretation of a Certificate of Classification, or any other document or information issued by the Society in connection with its Services, is governed by the Rules of the Society, which is the sole subject entitled to make such interpretation. Any disagreement on technical matters between the Interested Party and the Surveyor in the carrying out of his functions shall be raised in writing as soon as possible with the Society, which will settle any divergence of opinion or dispute.

3.3. The classification of a Ship, or the issuance of a certificate or other document connected with classification or certification and in general with the performance of Services by the Society shall have the validity conferred upon it by the Rules of the Society at the time of the assignment of class or issuance of the certificate; in no case shall it amount to a statement or warranty of seaworthiness, structural integrity, quality or fitness for a particular purpose or service of any Ship, structure, material, equipment or machinery inspected or tested by the Society.

3.4. Any document issued by the Society in relation to its activities reflects the condition of the Ship or the subject of certification or other activity at the time of the check.

3.5. The Rules, surveys and activities performed by the Society, reports, certificates and other documents issued by the Society are in no way intended to replace the duties and responsibilities of other parties such as Governments, designers, ship builders, manufacturers, repairers, suppliers, contractors or sub-contractors, Owners, operators, charterers, underwriters, sellers or intended buyers of a Ship or other product or system surveyed.

These documents and activities do not relieve such parties from any fulfilment, warranty, responsibility, duty or obligation (also of a contractual nature) expressed or implied or in any case incumbent on them, nor do they confer on such parties any right, claim or cause of action against the Society. With particular regard to the duties of the ship Owner, the Services undertaken by the Society do not relieve the Owner of his duty to ensure proper maintenance of the Ship and ensure seaworthiness at all times. Likewise, the Rules, surveys performed, reports, certificates and other documents issued by the Society are intended neither to guarantee the buyers of the Ship, its components or any other surveyed or certified item, nor to relieve the seller of the duties arising out of the law or the contract, regarding the quality, commercial value or characteristics of the item which is the subject of transaction.

In no case, therefore, shall the Society assume the obligations incumbent upon the above-mentioned parties, even when it is consulted in connection with matters not covered by its Rules or other documents.

In consideration of the above, the Interested Party undertakes to relieve and hold harmless the Society from any third party claim, as well as from any liability in relation to the latter concerning the Services rendered.

Insofar as they are not expressly provided for in these General Conditions, the duties and responsibilities of the Owner and Interested Parties with respect to the services rendered by the Society are described in the Rules applicable to the specific Service rendered.

Article 4

4.1. Any request for the Society's Services shall be submitted in writing and signed by or on behalf of the Interested Party. Such a request will be considered irrevocable as soon as received by the Society and shall entail acceptance by the applicant of all relevant requirements of the Rules, including these General Conditions. Upon acceptance of the written request by the Society, a contract between the Society and the Interested Party is entered into, which is regulated by the present General Conditions.

4.2. In consideration of the Services rendered by the Society, the Interested Party and the person requesting the service shall be jointly liable for the payment of the relevant fees, even if the service is not concluded for any cause not pertaining to the Society. In the latter case, the Society shall not be held liable for non-fulfilment or partial fulfilment of the Services requested. In the event of late payment, interest at the legal current rate increased by 1.5% may be demanded.

4.3. The contract for the classification of a Ship or for other Services may be terminated and any certificates revoked at the request of one of the parties, subject to at least 30 days' notice to be given in writing. Failure to pay, even in part, the fees due for Services carried out by the Society will entitle the Society to immediately terminate the contract and suspend the Services.

For every termination of the contract, the fees for the activities performed until the time of the termination shall be owed to the Society as well as the expenses incurred in view of activities already programmed; this is without prejudice to the right to compensation due to the Society as a consequence of the termination.

With particular reference to Ship classification and certification, unless decided otherwise by the Society, termination of the contract implies that the assignment of class to a Ship is withheld or, if already assigned, that it is suspended or withdrawn; any statutory certificates issued by the Society will be withdrawn in those cases where provided for by agreements between the Society and the flag State.

Article 5

5.1. In providing the Services, as well as other correlated information or advice, the Society, its Surveyors, servants or agents operate with due diligence for the proper execution of the activity. However, considering the nature of the activities performed (see art. 2.4), it is not possible to guarantee absolute accuracy, correctness and completeness of any information or advice supplied. Express and implied warranties are specifically disclaimed.

Therefore, except as provided for in paragraph 5.2 below, and also in the case of activities carried out by delegation of Governments, neither the Society nor any of its Surveyors will be liable for any loss, damage or expense of whatever nature sustained by any person, in tort or in contract, derived from carrying out the Services.

5.2. Notwithstanding the provisions in paragraph 5.1 above, should any user of the Society's Services prove that he has suffered a loss or damage due to any negligent act or omission of the Society, its Surveyors, servants or agents, then the Society will pay compensation to such person for his proved loss, up to, but not exceeding, five times the amount of the fees charged for the specific services, information or opinions from which the loss or damage derives or, if no fee has been charged, a maximum of AED5,000 (Arab Emirates Dirhams Five Thousand only). Where the fees charged are related to a number of Services, the amount of the fees will be apportioned for the purpose of the calculation of the maximum compensation, by reference to the estimated time involved in the performance of the Service from which the damage or loss derives. Any liability for indirect or consequential loss, damage or expense is specifically excluded. In any case, irrespective of the amount of the fees charged, the maximum damages payable by the Society will not be more than AED5,000,000 (Arab Emirates Dirhams Five Millions only). Payment of compensation under this paragraph will not entail any admission of responsibility and/or liability by the Society and will be made without prejudice to the disclaimer clause contained in paragraph 5.1 above.

5.3. Any claim for loss or damage of whatever nature by virtue of the provisions set forth herein shall be made to the Society in writing, within the shorter of the following periods: (i) THREE (3) MONTHS from the date on which the Services were performed, or (ii) THREE (3) MONTHS from the date on which the damage was discovered. Failure to comply with the above deadline will constitute an absolute bar to the pursuit of such a claim against the Society.

Article 6

6.1. These General Conditions shall be governed by and construed in accordance with United Arab Emirates (UAE) law, and any dispute arising from or in connection with the Rules or with the Services of the Society, including any issues concerning responsibility, liability or limitations of liability of the Society, shall be determined in accordance with UAE law. The courts of the Dubai International Financial Centre (DIFC) shall have exclusive jurisdiction in relation to any claim or dispute which may arise out of or in connection with the Rules or with the Services of the Society.

6.2. However,

(i) In cases where neither the claim nor any counterclaim exceeds the sum of AED300,000 (Arab Emirates Dirhams Three Hundred Thousand) the dispute shall be referred to the jurisdiction of the DIFC Small Claims Tribunal; and

(ii) for disputes concerning non-payment of the fees and/or expenses due to the Society for services, the Society shall have the right to submit any claim to the jurisdiction of the Courts of the place where the registered or operating office of the Interested Party or of the applicant who requested the Service is located.

In the case of actions taken against the Society by a third party before a public Court, the Society shall also have the righ t to summon the Interested Party or the subject who requested the Service before that Court, in order to be relieved and held harmless according to art. 3.5 above.

Article 7

7.1. All plans, specifications, documents and information provided by, issued by, or made known to the Society, in connection with the performance of its Services, will be treated as confidential and will not be made available to any other party other than the Owner without authorisation of the Interested Party, except as provided for or required by any applicable international, European or domestic legislation, Charter or other IACS resolutions, or order from a competent authority. Information about the status and validity of class and statutory certificates, including transfers, changes, suspensions, withdrawals of class, recommendations/conditions of cl ass, operating conditions or restrictions issued against classed ships and other related information, as may be required, may be published on the website or released by other means, without the prior consent of the Interested Party.
Information about the status and validity of other certificates and statements may also be published on the website or released by other means, without the prior consent of the Interested Party.

7.2. Notwithstanding the general duty of confidentiality owed by the Society to its clients in clause 7.1 above, the Society's c lients hereby accept that the Society may participate in the IACS Early Warning System which requires each Classification Society to provide other involved Classification Societies with relevant technical information on serious hull structural and engineering systems failures, as defined in the IACS Early Warning System (but not including any drawings relating to the ship which may be the specific propert y of another party), to enable such useful information to be shared and used to facilitate the proper working of the IACS Early Warning System. The Society will provide its clients with written details of such information sent to the involved Classification Societies.

7.3. In the event of transfer of class, addition of a second class or withdrawal from a double/dual class, the Interested Party undertakes to provide or to permit the Society to provide the other Classification Society with all building plans and drawings, certificat es, documents and information relevant to the classed unit, including its history file, as the other Classification Society may require for the purpose of classification in compliance with the applicable legislation and relative IACS Procedure. It is the Owner's duty t o ensure that, whenever required, the consent of the builder is obtained with regard to the provision of plans and drawings to the new Society, either by way of appropriate stipulation in the building contract or by other agreement.
In the event that the ownership of the ship, product or system subject to certification is transferred to a new subject, the latter shall have the right to access all pertinent drawings, specifications, documents or information issued by the Society or which has come to the knowledge of the Society while carrying out its Services, even if related to a period prior to transfer of ownership.

Article 8

8.1. Should any part of these General Conditions be declared invalid, this will not affect the validity of the remaining provisions.

SECTION 1

SECTION 2

Section 1

1 GENERAL

1.1 PREAMBLE

The purpose of these Rules is to supplement the international provisions of SOLAS and subsidiary IMO Codes for ships equipped with Fuel Cells (FC) power generation systems using low-flashpoint fuels.

It is acknowledged that international regulations and applicable standards for Fuel Cells (FC) are still being developed, while new technologies are rapidly evolving.

FC-SHIPS is based upon sound principles of naval architecture and marine engineering, taking into account current technologies, operational experience and R&D results.

FC-SHIPS addresses all areas that need special consideration for the design, construction and operation of FC for power generation systems on ships, using a prescriptive approach supplemented by risk-based methodologies.

1.2 SCOPE

The scope of these Rules is to specify provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using FC power generation systems using low-flashpoint fuel, aimed at minimising the risk to the ship, its crew and the environment, having regard to the nature of the fuels involved.

FC-SHIPS addresses the hazards related to the installation of FC power generation systems using a variety of gaseous and liquid fuels, such as natural gas (LNG) and diesel fuels.

FC technologies are under continuous development, as well as the relevant international regulatory framework (e.g. IMO IGF Code), therefore the prescriptive requirements of Section 1 are to be supplemented - on a case by case basis - by additional provisions following the Risk-Based approach specified in Section 2.

These Rules apply to ships [classed by the Society and] complying with the goals and functional requirements specified of Section 1 and Section 2.

1.3 APPLICATION

These Rules apply to the arrangement, installation, control and monitoring of FC power generation systems in ships, using gas as fuel and oxygen from ambient air as oxidant.

FC fuel can be obtained from LNG, methanol, propane, hydrogen or other gases. The use on board of both gas- and hydrocarbon-based fuels is to be subject to special examination by the Society.

FC fuel may be stored on board in gaseous compressed state, or liquid state, or other conditions (e.g. metal hydride hydrogen storage) and supplied to the FC directly, or after reforming, or after other types of fuel processing.

In this context, FC-SHIPS applies only to FC power generation systems in ships using low-flashpoint fuel other than ships covered by the IGC Code.

FC-SHIPS is intended to supplement the applicable provisions of:

- the International Convention for the Safety of Life at Sea (SOLAS) 1974 and its Protocol of 1988, as amended
- the latest version of the International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code), as amended.

Compliance with the provisions of Tasneef Rules Pt C, Ch 1, App 7 is cross referenced where applicable.

In general, FC-SHIPS applies to FC installations on ships - including all their relevant machinery, equipment and systems - and to the interfaces between FC installations and the other parts of the ship, which are to comply with the applicable Sections of the hull and machinery Rules.

The use of FC system installations in ships requires additional acceptance by the Administration of the State whose flag the ship is entitled to fly.

1.4 CLASSIFICATION OPTIONS

FC-SHIPS includes two alternative options, to be selected depending on the use of FC power generation and supply systems:

- FC-SHIPS / ESSENTIAL
- FC-SHIPS / NON-ESSENTIAL

FC power generation and supply systems can be used either for essential services - including propulsion, control, manoeuvring, safety of the ship, emergency services – or for non-essential services.

FC power generation systems intended for essential services are to be maintained and not become inoperative, and consequently are to be specifically considered in terms of reliability, availability and redundancy to satisfy the safety and the environmental requirements of the ship.

The option FC-SHIPS / ESSENTIAL is to be selected when the FC power generation systems are intended for essential services and satisfy the provisions of Section 1 and Section 2.

The option FC-SHIPS / NON-ESSENTIAL is to be selected when the FC power generation systems are intended for non-essential services and satisfy the relevant provisions of Section 1 and Section 2.

Design and survey requirements for ships with options FC-SHIPS / ESSENTIAL and FC-SHIPS / NON-ESSENTIAL are defined in Section 1.

1.5 DEFINITIONS

Unless otherwise stated below, definitions are as in SOLAS chapter II-2 and Resolution MSC.391(95) Adoption of the International Code of Safety for Ships using gases or other low-flashpoint fuels (IGF Code):

- *Accident* means an uncontrolled event that may entail the loss of human life, personal injuries, environmental damage or the loss of assets and financial interests. (IGF Code 2.2.1)
- *Bunkering* means the transfer of liquid or gaseous fuel from land based or floating facilities into a ships' permanent tanks or connection of portable tanks to the fuel supply system. (IGF Code 2.2.3)
- *Certified safe type* means electrical equipment that is certified safe by the relevant authorities recognized by the Administration for operation in a flammable atmosphere based on a recognized standard. (IGF Code 2.2.4)
- *CNG* means compressed natural gas (IGF Code 2.2.5 and 2.2.26)
- *CGH2* means compressed gaseous hydrogen
- *Control station* means those spaces defined in SOLAS chapter II-2 and additionally, as per IGF Code, the engine control room (IGF Code 2.2.6)
- *Design temperature for selection of materials* is the minimum temperature at which liquefied gas fuel may be loaded or transported in the liquefied gas fuel tanks (IGF Code 2.2.7)
- *Design vapour pressure* "P0" is the maximum gauge pressure, at the top of the tank, to be used in the design of the tank (IGF Code 2.2.8)
- *Double block and bleed valve* means a set of two valves in series in a pipe and a third valve enabling the pressure release from the pipe between those two valves. The arrangement may also consist of a two-way valve and a closing valve instead of three separate valves (IGF Code 2.2.9)
- *Effluent* means products of combustion plus the excess air being discharged from gas utilization equipment
- *Enclosed space* means any space within which, in the absence of artificial ventilation, the ventilation will be limited and any explosive atmosphere will not be dispersed naturally (IGF Code 2.2.11)
- *ESD* means emergency shutdown (IGF Code 2.2.12)
- *Essential service* (ref. e.g SOLAS Chapter II-1, Part C Reg.26), especially in the case of unconventional arrangements, means main propulsion machinery, auxiliary machinery essential for the power transmission to the propulsion, power sufficient to give the ship a navigable speed, ship control, and guarantee the safety of the ship and of the persons on board
- *Explosion* means a deflagration event of uncontrolled combustion (IGF Code 2.2.13)
- *Explosion pressure relief* means measures provided to prevent the explosion pressure in a container or an enclosed space exceeding the maximum overpressure the container or space is designed for, by releasing the overpressure through designated openings (IGF Code 2.2.14)
- *Fail-safe* is the ability to sustain a failure without causing loss of equipment, injury to personnel or loss of operating time
- *FC* means fuel cell. A fuel cell is a source of electrical power in which the chemical energy of a fuel is converted directly into electrical energy by electrochemical oxidation. A FC installation may consist of one or more FC systems
- *FC system* means the FC, the complete installation of FC fuel containment, FC fuel piping, relevant machinery, electrical and automation systems and the complete system required to transform the energy of the fuel to electric power
- *Filling limit (FL)* means the maximum liquid volume in a fuel tank relative to the total tank volume when the liquid fuel has reached the reference temperature (IGF Code 2.2.16)
- *Fuel cell installation* includes all components required for the production of energy by the FC and the FC ancillary systems, such as the FC system, the FC gas fuel system, the FC water supply system, the FC heat recovery system and the power conversion system
- *Fuel cell module* includes the assembly of one or more FC stacks, electrical connections and systems for command, control and monitoring
- *Fuel cell power system* means a system typically composed by subsystems such as FC module, oxidant processing system, fuel processing system, thermal management system, water

treatment system, power conditioning system and relevant control systems

- *Fuel cell space* in this Section is used for machinery spaces containing FC installations
- *Fuel cell stack* consist of an assembly of FC, separators, cooling devices, manifolds and supporting structures that electrochemically converts, typically, hydrogen-rich gas and air reactants to d.c. power, heat, water and other by-products
- *Fuel containment system* is the arrangement for the storage of fuel including tank connections. It includes where fitted, a primary and secondary barrier, associated insulation and any intervening spaces, and adjacent structure if necessary for the support of these elements. If the secondary barrier is part of the hull structure it may be a boundary of the fuel storage hold space

  The spaces around the fuel tank are defined as follows:

  .1 Fuel storage hold space is the space enclosed by the ship's structure in which a fuel containment system is situated. If tank connections are located in the fuel storage hold space, it will also be a tank connection space;

  .2 Interbarrier space is the space between a primary and a secondary barrier, whether or not completely or partially occupied by insulation or other material; and

  .3 Tank connection space is a space surrounding all tank connections and tank valves that is required for tanks with such connections in enclosed spaces (IGF Code 2.2.15)

- *Fuel processing system* means a system that converts and/or conditions the fuel as stored in the on board fuel storage systems into fuel suitable for operation in the FC stack
- *Fuel preparation room* means any space containing pumps, compressors and/or vaporizers for fuel preparation purposes (IGF Code 2.2.17).
- *Gas* means a fluid having a vapour pressure exceeding 0.28 MPa absolute at a temperature of 37.8°C. (IGF Code 2.2.18)
- *Gas consumer* means any unit within the ship using gas as a fuel (IGF Code 2.2.19)
- *Gas safe spaces* are those spaces considered inherently gas safe under all conditions (normal and abnormal) as a consequence of their arrangement. Specifically, in a gas safe space a single failure cannot lead to release of fuel gas into the space
- *Hazardous area* means an area in which an explosive gas atmosphere is or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of equipment. (IGF Code 2.2.21 – see also Sec 1, [10.3])
- *High pressure* means a maximum working pressure greater than 1.0 MPa (IGF Code 2.2.22).
- *Hydrogen handling system* is the system that processes, conditions, and/or conveys hydrogen - or hydrogen-rich gas - to the FC
- *Independent tanks* are self-supporting tanks, not forming part of the ship's hull and not essential to the hull strength (IGF Code 2.2.23)
- *IEC* means the International Electrotechnical Commission
- *IGC Code* means the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, as amended
- *IGF Code* means the International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels
- *LEL* means the lower explosive limit (IGF Code 2.2.24)
- *LNG* means liquefied natural gas (IGF Code 2.2.26)
- *Loading limit (LL)* means the maximum allowable liquid volume relative to the tank volume to which the tank may be loaded (IGF Code 2.2.27)
- *Low-flashpoint fuel* means gaseous or liquid fuel having a flashpoint lower than otherwise permitted under paragraph 2.1.1 of SOLAS regulation II-2/4 (IGF Code 2.2.28)
- *MARVS* means the maximum allowable relief valve setting (IGF Code 2.2.29)
- *MAWP* means the maximum allowable working pressure of a system component or tank (IGF Code 2.2.30)
- *Membrane tanks* are non-self-supporting tanks that consist of a thin liquid and gas tight layer (membrane) supported through insulation by the adjacent hull structure (IGF Code 2.2.31)
- *Main tank valve* means a remote operated valve on the FC fuel outlet from a FC fuel storage tank, located as close as possible to the tank outlet point
- *Master fuel valve* means an automatic valve in the FC fuel supply line to each FC located outside the FC space and as close as possible to the fuel storage
- *Non-hazardous* area means an area in which an explosive gas atmosphere is not expected to be present in quantities such as to require special precautions for the construction, installation and use of equipment (IGF Code 2.2.33)

- *Open deck* means a deck having no significant fire risk that at least is open on both ends/sides, or is open on one end and is provided with adequate natural ventilation that is effective over the entire length of the deck through permanent openings distributed in the side plating or deckhead (IGF Code 2.2.34)
- *Oxidant processing system* is a system to treat and process the incoming oxidant (generally air) supply for use within the ranges accepted by the FC module
- *Risk* is an expression for the combination of the likelihood and the severity of the consequences (IGF Code 2.2.35)
- *Reference temperature* means the temperature corresponding to the vapour pressure of the fuel in a fuel tank at the set pressure of the pressure relief valves (PRVs) (IGF Code 2.2.36)
- *Power conditioning system* consist of the equipment used to adapt the electrical energy produced to the requirements specified by the manufacturer
- *Pressure Relief Valve* is a pressure relief device that opens at a pre-set pressure level and can re-close
- *Safe location* means a location (e.g. on open deck) remote from any source of ignition where flammable gases, vapours or liquids can be released to the atmosphere and are expected to be diluted by natural ventilation, without being ventilated in other areas where potential sources of ignitions are present
- *Secondary barrier* is the liquid-resisting outer element of a fuel containment system designed to afford temporary containment of any envisaged leakage of liquid fuel through the primary barrier and to prevent the lowering of the temperature of the ship's structure to an unsafe level (IGF Code 2.2.37)
- *Semi-enclosed space* means a space where the natural conditions of ventilation are notably different from those on open deck due to the presence of structure such as roofs, windbreaks and bulkheads and which are so arranged that dispersion of gas may not occur (IGF Code 2.2.38)
- *Source of release* means a point or location from which a gas, vapour, mist or liquid may be released into the atmosphere so that an explosive atmosphere could be formed (IGF Code 2.2.39)
- *Thermal management system* are systems to provide cooling and/or heat exchange to maintain thermal equilibrium within the FC power system, as well as the recovery of excess heat and heating the FC during start-up
- *Unacceptable loss of power* means that it is not possible to sustain or restore normal operation of the propulsion machinery in the event of one of the essential auxiliaries becoming inoperative, in accordance with SOLAS regulation II-1/26.3 (IGF Code 2.2.40)
- *Vapour pressure* is the equilibrium pressure of the saturated vapour above the liquid, expressed in MPa absolute at a specified temperature (IGF Code 2.2.41)
- *Water treatment system* provides the treatment and purification of recovered or added water for use within the FC power systems, as necessary.

1.6 DOCUMENTATION TO BE SUBMITTED

Table 1 lists the plans, information, drawings, documents, etc. which are to be submitted in addition to the information required in the other items of the Rules for the parts of the ship not affected by FC installations.

Table 1: Documents to be submitted

I/A (1)	Subject	Document
I	GENERAL SPECIFICATION	FC power system design philosophy including information on the machinery configuration, FC room arrangement, fuel arrangement, shutdown criteria (if applicable), redundancy considerations etc. Comprehensive description and specification of physical environment and operating conditions (e.g. fuel and water supply characteristics, heat management, etc.); Description of the different operating configurations with indication of the FC developed power Description of FC system and components, including FC fuel handling, transportation and storage systems Any other general information related to the FC power system
A	FC FUEL GAS SYSTEM	FC fuel gas system Cause and effect diagram Test program for safety functions

A	FC FUEL GAS ARRANGEMENT	FC fuel gas system general arrangement plan, including: • FC machinery spaces containing FC power systems and installations FC gas fuel containment, processing and preparation systems: • FC gas tanks and capacity plan; FC gas containment systems • FC gas pump and compressor rooms • FC gas bunkering pipes with shore connections • FC fuel tank hatches, ventilation pipes and any other openings to gas tanks • ventilating pipes, doors and openings to FC rooms, compressor rooms and other hazardous areas • entrances, air inlets and openings to FC rooms installations
I	FC FUEL GAS SYSTEM	FC fuel gas system operational manual including procedures for: • bunkering • gas freeing and inerting • normal operation • emergency operation
A	FC FUEL GAS SYSTEM	FC fuel gas tanks production process including: Drawings of: • tanks • supports and stays • secondary barriers • insulation • marking plates FC fuel gas tank design analysis: • specification of design loads and structural analysis of gas tanks • complete stress analysis for independent tanks (type B and type C, as applicable) FC fuel gas tank non-destructive testing (NDT) plan including: • information about strength and tightness testing • specification of stress relieving procedures, as applicable (thermal or mechanical). FC fuel gas tank welding procedures FC fuel gas tank material specifications including connected pipes
A	FC FUEL GAS SYSTEM	FC fuel gas tank safety relief valves and associated ventilation piping specification, detailed drawing and piping FC fuel capacity analysis including back pressure
A	FC FUEL GAS SYSTEM	FC fuel gas tank gas freeing and purging system piping diagram
A	FC FUEL GAS SYSTEM	FC fuel gas tank control and monitoring system
A	FC FUEL GAS SYSTEM	FC fuel gas piping system: Pipe routing Piping distribution diagrams and thermal stress analysis (if and when design temperature is below -110°C) Piping diagram (including ventilation lines for safety relief valves or similar piping, and ducts for FC gas pipes)
A	FC FUEL GAS SYSTEM	Capacity requirements and analysis P&ID diagrams Piping systems schematics, including: • FC fuel • FC gas piping system located in the machinery spaces, including double wall piping or duct system • inert gas piping system (if fitted) • vent lines of safety relief system • cooling / heating water system in connection with FC fuel system (if fitted) • drawings and specifications of fire / thermal insulation (where installed) Specification of electrical bonding of piping Specification of heat tracing arrangements (if fitted)

I	FC FUEL GAS SYSTEM	FC fuel gas piping system - Specification of valves, flanges and fittings including offsets, loops, bends, expansion elements such as bellows and slip joints (only inside tanks). For valves intended for service with a design temperature below -55°C, documentation of leak test and functional test at design temperature (type test) is to be included
A	FC FUEL GAS SYSTEM	Material, thickness and joints of the gas piping Calculations for safety relief valves and pressure/vacuum relief valves
A	FC FUEL GAS SYSTEM	FC fuel gas system drip trays - System arrangement plan – Specification and layout of hull protection beneath liquid piping where leakages may be anticipated (e.g. at shore connections, at pump seals, etc.)
A	FC FUEL GAS SYSTEM	Cooling system - Piping diagram in connection with fuel gas system
A	FC FUEL GAS SYSTEM	Heating system - Piping diagram in connection with fuel gas system
A	FC FUEL GAS SYSTEM	Fuel gas compressor control and monitoring system
A	FC FUEL GAS SYSTEM	Fuel gas driven engines - Failure mode and effect analysis - Examination of all possible faults affecting the combustion process
A	FC FUEL GAS SYSTEM	Exhaust gas system - Piping diagram
A	VENTILATION	Ducting diagrams and plans for spaces containing FC gas installations: • FC gas pipe ducts led through spaces with FC fuel installations and FC fuel storage tanks below deck, including arrangements and specifications, capacity and location of fans and their motors • Systems for FC gas freeing and purging • Any ventilation arrangements in the FC stacks / modules • Air inlet / exhaust systems, including arrangement and filters Drawings and material specifications of rotating parts and casings (e.g. fans and ventilators)
A	FUEL CELLS DESIGN	FC power units drawings and arrangements, including dimensions, materials, weights, operating temperatures and pressures, etc.
I	FUEL CELLS DESIGN	FC functional description: • FC type and principles • Specification of FC modules, including outer surface temperatures • Voltage and current levels in different parts and components of the FC modules, short circuit evaluation and earthing principles • FC modules maintenance requirements (e.g. stack replacement) Expected FC module life time, availability and MTBF (e.g. degradation rate curve)
I	FUEL CELLS DESIGN	Description of design criteria, including • Design pressures (e.g. safety valve, pressure vessels) and temperatures • Overall volume • Fluid exchange requirements • Structural requirement and loads on FC stacks, as applicable Sequence of operations for starting and shut-down
I	FUEL CELLS DESIGN	Arrangement plans and instructions, including: • Manufacturer’s recommendations on location and design of the FC power system foundation and height • FC enclosure requirements • FC ventilation requirements, exhaust openings and clearances around air supply • Clearances for FC maintenance, servicing and proper operation Manufacturer’s additional special instructions, if any
A	FUEL CELLS DESIGN	Interconnection diagrams / system schematics, providing full information on FC external connections (electrical power supply, fuel supply, water supply, control and monitoring equipment, exhaust venting, inlet/outlet ventilation, etc.)
A	FUEL CELLS DESIGN	Diagrams with minimum and maximum design FC fuel supply pressures, with relevant monitoring and measuring system
A	FUEL CELLS DESIGN	Drawings and specification of the FC gas supply system to each gas utilization equipment
I	FUEL CELLS DESIGN	FC fuel system data (storage pressure, temperature, LEL, toxicity, corrosion and any other important safety related characteristics) Diagram of the oxidant processing, supply and exhaust system

A	EXPLOSION PROTECTION	Hazardous area classification drawing and arrangement, including air-lock location, construction details of electric equipment, ventilating inlets/outlets, doors, openings, and alarm equipment
A	EXPLOSION PROTECTION	Gastight bulkhead penetrations - Detailed drawing
I	EXPLOSION PROTECTION	Explosion protection • System arrangement plan of electrical equipment in hazardous areas • Single line diagrams for all intrinsically safe circuits, for each circuit, including data for verification of the compatibility between the barrier and the field components • List of non-certified safe electrical equipment to be disconnected for ESD protected machinery spaces • Documentation to demonstrate the fulfilment of the limitation of explosion consequences
A	FIRE SAFETY	Fixed gas detection and alarm system arrangement plan Call points and alarm plan and arrangement
A	FIRE SAFETY	Structural fire protection drawing in respect of FC gas installation arrangements
A	FIRE SAFETY	Fixed and automatic fire extinguishing system plans and documents of FC spaces
A	FIRE SAFETY	External surface protection water-spraying system
A	FIRE SAFETY	Bunkering station fire-fighting system
A	FIRE SAFETY	Fire / smoke detection and alarm system for FC fuel storage tanks and ventilation trunks
A	ELECTRICAL / SAFETY	FC electrical installations drawings and circuit diagrams Electrical supply requirements and connections Table of Ex-installations
A	ELECTRICAL / SAFETY	Description of the safeguards, interconnection diagrams, interlocking functions for potentially hazardous situations Description of the safeguarding and of the requirements for programming and functional testing
A	ELECTRICAL / SAFETY	Cable data sheet and design drawing, if not already type approved by the Society
A	ELECTRICAL / SAFETY	Electrical system design concept and documentation, including the electrical power system's overall properties, to assess the compliance with the selected option FC SHIP ESSENTIAL / NON-ESSENTIAL. Such documentation is required also for the risk-based approach, including: • configuration of the system in all operating modes • power distribution concept for different ship systems / services (e.g. essential, manoeuvring, emergency services…) • voltage and frequency variations during steady state and transient modes • description of current DC components generated by the FC • black-out and dead ship recovery procedure • active and reactive load capacities • system behaviour in the relevant failure modes The system reliability and availability is to be documented following a risk-based approach as per Section 2, supplemented by the results from factory and dockside testing
A	ELECTRICAL / SAFETY	System block diagram (topology) FC power supply arrangement Instrument and equipment list of safety devices with relevant set points Schematic description of input / output circuits
A	ELECTRICAL / SAFETY	Specification of the command, control and monitoring of safety systems, including ESD, fire detection and fire extinguishing systems
A	CONTROL AND MONITORING	General – FC control system philosophy description FC control system functional description FC control and monitoring system documentation Diagrams showing the local and remote control systems and automation systems with relevant power supply arrangements Control software quality assessment plan and certification
A	RISK-BASED DESIGN	FMEA of the whole FC installations
A	RISK-BASED DESIGN	Test procedures of safety-critical items, in particular those related to the gas system as ascertained by the FMEA.

I	RISK-BASED DESIGN	The risk-based design is to be carried out with ref. to Section 2, depending on the selected option: FC SHIP ESSENTIAL / NON-ESSENTIAL. See Section 2 for the documentation is to be submitted, as applicable.
(1) A = to be submitted for approval, in four copies I = to be submitted for information, in duplicate		

In addition to this list, other components, special components, equipment, etc. may be required to be documented and submitted to the Society, e.g. as a result of the risk-based considerations carried out as per Section 2.

1.7 CERTIFICATION

Table 2 lists the [safety] certification requirements to be submitted, in compliance with the Rules of the Society.

Table 2: Certification requirements

Description
FC system (including Type-Approval by the Society)
Pressure equipment
Valves (hydrogen valves in gas-safe spaces are to be leakage tested with hydrogen)
Pumps and compressors
Safety certificates for electrical equipment located in gas-dangerous spaces/zones
Flammable gas detection system
Electrical components datasheet / type approval certificates
Command, control and monitoring of FC safety systems
Software quality plan

1.8 INSTALLATION AND TESTING

Prior to servicing, comprehensive tests of FC systems are to be carried out to assess their safe and environmentally-friendly design, construction and operation.

The details of these tests are to be defined, case by case, depending on:

- FC technology,
- FC system design,
- FC construction and installation principles.

The tests are to be referred to all parts, components, special components, equipment or systems mentioned in FC-SHIPS, as specified in the drawings, the plans and the related information which are to be submitted in accordance with Table 1 above.

A complete test program is to be documented and submitted to the Society for approval, covering at least the following:

Table 3: Installation and Testing - Documentation to be submitted

I/A	Document
A	Test procedure and schedule (ref. e.g. IEC standard 62282-3-1 “Stationary fuel cell power systems- Safety”), based upon the following documentation: • Type approval requirements for the component installation • Assembly or arrangement drawings • Detailed drawing, including all valves, fittings, supports, etc. • Piping installation manual of all piping systems for handling FC fuel • Testing of command, control and monitoring of safety systems
I	• Specification of environmental conditions to be complied with prior to testing, taking into account the expected in-service operations on board. • Data sheet of components
A	Non-Destructive Testing (NDT) plan
A	Procedure for functional tests at manufacturer’s
A	Procedure for functional tests on board - at quayside and/or sea trials
A	Testing requirements for systems and components representing significant risks, as a result of the risk analysis carried out in accordance with Section 2
I	Spreadsheet template for test reports and results
(1) A = to be submitted for approval, in four copies I = to be submitted for information, in duplicate	

Additional requirements are contained Sec 1, [13.1] of FC-SHIPS, which includes further specifications for initial installation and testing, as well as life-cycle periodical functional testing requirements.

1.9 OPERATION, INSPECTION AND MAINTENANCE

An Operating Manual of the FC systems is to be kept on board.

A Plan for Systematic Life-Cycle Maintenance and Functional Testing is to be submitted for approval. This plan is to be included in the ship’s maintenance system, is to be regularly updated and kept on board. This plan is to include:

- scope, procedure and schedule for periodical testing,
- the parameters to be monitored,
- test results and dates of verification,
- all instrumentation, automation and control systems involved.

The specified test intervals are to reflect the consequences of expected type of failure and MTBF involving each FC system. In any case:

- Functional testing of critical alarms is not to exceed 3 month intervals.
- Functional testing of non-critical alarms is not to exceed 12 month intervals.

Table 4 lists the documents to be submitted.

Table 4: Operation, inspection and maintenance documents

I/A	Documents
I	Operating manual of the FC installation, including: — Instruction for actions to be taken prior to servicing the FC modules — FC starting-up procedures, from dead ship condition or stand-by — FC system normal operation and stop — FC system emergency operations, including emergency stop of the gas fuel utilization equipment. — Countermeasures in case of gas detection outside the gas containment systems (e.g. in the machinery spaces, in the double wall pipes or ducts, in the ventilation hoods or casings…)
I	Maintenance procedure of: — FC power system and components — FC bunkering and refuelling system — electrical installations in hazardous areas — FC fuel containment systems and related equipment - including gas tightness, verification and calibration of gas detection systems
A	Plan for Systematic Life-Cycle Maintenance and Functional Testing, based upon component deterioration rate data
I	— Instrumentation and parts list — Recommended spare parts list by the manufacturer
(1)	A = to be submitted for approval, in four copies I = to be submitted for information, in duplicate

1.10 REFERENCES

FC-SHIPS makes explicit reference to the provisions of the IGC Code, as well as the Tasneef Rules for the Classification of Ships, which are considered applicable to FC installations.

Additional Hydrogen and FC specific reference is available in the following international Standards, guidelines, recommended practices and technical information:

IEC 62282 - Fuel cell technologies

IEC 62282-1:2012 “Terminology”

IEC 62282-2:2012 “Fuel cell modules”

IEC 62282-3-100:2012 “Stationary fuel cell power systems - Safety”

IEC 62282-3-200:2015 “Stationary fuel cell power systems – Performance test methods”

IEC 62282-3-300:2012 “Stationary fuel cell power systems – Installations”

IEC 62282-7-1:2010 “Single cell test methods for polymer electrolyte fuel cell (PEFC)”

IEC 62282-7-2:2014 “Single cell and stack performance tests for solid oxide fuel cells (SOFC)”

IEC 60092-502:1999: Electrical Installations in Ships – Tankers – Special Features

IEC 60079-10-1:2008: Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres

IEC 60079-17:2007: Explosive atmospheres - Part 17: Electrical installations inspection and maintenance

ISO 14687-3:2014 “Proton exchange membrane (PEM) fuel cell applications for stationary appliances”

ISO 16110 - Hydrogen generators

ISO 16110-1:2007 “Hydrogen generators using fuel processing technologies - Safety”

ISO 23273-1:2006: Fuel cell road vehicles – safety specifications; Part 1: Vehicle functional safety

ISO 23273-2:2006: Fuel cell road vehicles – safety specifications; Part 2: Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen

ISOTR15916 Basis considerations for the safety of hydrogen systems

ISO 15399 Gaseous Hydrogen - Cylinders and tubes for stationary storage

ISO 11114-4:2005: Transportable gas cylinders – Compatibility of cylinders and valve materials with gas contents – Part 4: Test methods for hydrogen compatibility with metals

ISO 26142:2010 Hydrogen detection apparatus – Stationary applications.

ISO/TS 15869: 2009: Gaseous hydrogen and hydrogen blends – Land vehicle fuel tanks

ISO 15649:2001 Piping for petroleum and natural gas industries (used also for hydrogen

EN ISO 14726:2008: Ships and marine technology. Identification colours for the content of piping systems

DIN EN 62282-2 based on IEC 62282-2 standard

SAE J2578 (January 2009): Recommended practice for general fuel cell vehicle safety

SAE J2579 (January 2009): Technical Information Report for fuel systems in fuel cell and other hydrogen vehicles

2 SAFETY PRINCIPLES - DESIGN

Reference is made to the IGF Code – IMO MSC 95/22/Add.1 Annex 1 – Sect 2.3 Alternative design, which contains functional requirements for all appliances and arrangements related to the usage of low-flashpoint fuels – which are considered relevant also to FC installations.

More specifically:

Fuels, appliances and arrangements of low-flashpoint fuel systems may either:

- deviate from those set out in the IGF Code, or
- be designed for use of a fuel not specifically addressed in the IGF Code.

Such fuels, appliances and arrangements can be used provided that these meet the intent of the goal and functional requirements concerned, and provide an equivalent level of safety of the relevant chapters (ref. IGF Code 2.3.2).

According to the IGF Code, the equivalence of the alternative design is to be demonstrated as specified in SOLAS regulation II-1/55 and approved by the Administration. However, the Administration is not to allow operational methods or procedures to be applied as an alternative to a particular fitting, material, appliance, apparatus, item of equipment, or type thereof which is prescribed by the IGF Code (ref. IGF Code 2.3.3).

3 FUEL CELLS ESSENTIAL / NON-ESSENTIAL POWER GENERATION SYSTEMS

The IGF Code goal and functional Requirements (ref. IGF Code 3.1 and 3.2) – reported here below in *italics* for easy reference – are also applicable to the scope of FC-SHIPS, depending on the selected option:

- FC-SHIP / ESSENTIAL, or
- FC-SHIP / NON-ESSENTIAL.

The main difference between these two options consists in the assessment of the reliability, availability and redundancy of the FC installations supplying power to the ship’s essential systems.

The following definitions apply (ref. IGF Code, part A para 2.2.40 and SOLAS II-1/26.3):

a) “Unacceptable loss of power” means that it is not possible to sustain or restore normal operation of the propulsion machinery in the event of one of the essential auxiliaries becoming inoperative, in accordance with SOLAS regulation II-1/26.3 *“Means are to be provided whereby normal operation of propulsion machinery can be sustained or restored even though one of the essential auxiliaries becomes inoperative”.*

b) “Normal operational and habitable condition” is a condition under which the ship as a whole, the machinery, services, means and aids ensuring propulsion, ability to steer, safe navigation, fire and flooding safety, internal and external communications and signals, means of escape, and emergency boat winches, as well as the designed comfortable conditions of habitability are in working order and functioning normally.

The option FC-SHIP / ESSENTIAL is to be selected when the FC systems design ensures that any single failure of the FC system does not lead to loss of propulsion or auxiliary power for ship’s essential systems - which include:

- propulsion,
- ability to steer and manoeuver,
- safe navigation,
- fire and flooding safety,
- internal and external communication and signals,
- means of escape,
- emergency lifesaving appliances operations,
- designed essential comfortable conditions of habitability of the ship.

Propulsion and electrical power generating arrangements and installation are to be capable of sustained or restored operation in the event that a gas fuelled FC power generation system used to supply an essential service becomes inoperative.

The option FC-SHIP / ESSENTIAL also implies that, in case of a shut down due to a FC fuel leakage, the arrangement of the FC systems and spaces does not lead to a loss of propulsion or auxiliary power for essential systems.

The need of any power from the FC systems for restoration from a black-out or dead ship situation is to be identified, considered, documented and approved in each case. The necessary recovery arrangements and/or procedures are to be reported and explicitly approved.

Goal:

The main goal of the IGF Code is *“… to provide for safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery using gas or low-flashpoint fuel as fuel.”*

The same goal is therefore applicable to FC installations using gas or low-flashpoint fuel as fuel.

Functional requirements

The safety, reliability and dependability of the FC installations are to be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery.

A FMEA consistent with the "Tasneef Guide for FMEA" is to be carried out for the whole FC gas-fuelled system, including process system, electrical power supplies and control system, to check the potential existence of failure modes that can jeopardize the ship's safety.

The results of the FMEA are then to be used to establish a trial program.

Table 5 lists the applicability of functional requirements to FC-SHIP / ESSENTIAL and NON-ESSENTIAL options

Table 5: Applicability of Functional requirements:

FC-SHIPS / ESSENTIAL	FC-SHIPS /NON-ESSENTIAL	Functional requirements
X	X	*The safety, reliability and dependability of the systems are to be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery* (ref. IGF Code 3.2.1).
X	X	*The probability and consequences of fuel-related hazards are to be limited to a minimum through arrangement and system design, such as ventilation, detection and safety actions. In the event of gas leakage or failure of the risk reducing measures, necessary safety actions are to be initiated* (ref. IGF Code 3.2.2).
X		*The design philosophy is to ensure that risk reducing measures and safety actions for the gas fuel installation do not lead to an unacceptable loss of power* (ref. IGF Code 3.2.3).
X	X	*Hazardous areas are to be restricted, as far as practicable, to minimize the potential risks that might affect the safety of the ship, persons on board, and equipment* (ref. IGF Code 3.2.4).
X	X	*Equipment installed in hazardous areas is to be minimized to that required for operational purposes and are to be suitably and appropriately certified* (ref. IGF Code 3.2.5).
X	X	*Unintended accumulation of explosive, flammable or toxic gas concentrations are to be prevented* (ref. IGF Code 3.2.6).
X	X	*System components are to be protected against external damages* (ref. IGF Code 3.2.7).
X	X	*Sources of ignition in hazardous areas are to be minimized to reduce the probability of explosions* (ref. IGF Code 3.2.8).
X	X	*It is to be arranged for safe and suitable fuel supply, storage and bunkering arrangements capable of receiving and containing the fuel in the required state without leakage. Other than when necessary for safety reasons, the system is to be designed to prevent venting under all normal operating conditions including idle periods* (ref. IGF Code 3.2.9).
X	X	*Piping systems, containment and over-pressure relief arrangements that are of suitable design, construction and installation for their intended application are to be provided* (ref. IGF Code 3.2.10).
X		*Machinery, systems and components are to be designed, constructed, installed, operated, maintained and protected to ensure reliable operation* (ref. IGF Code 3.2.11).
X	X	*Fuel containment system and machinery spaces containing source that might release gas into the space are to be arranged and located such that a fire or explosion in either will not lead to an unacceptable loss of power or render equipment in other compartments inoperable* (ref. IGF Code 3.2.12).
X	X	*Suitable control, alarm, monitoring and shutdown systems are to be provided to ensure safe and reliable operation* (ref. IGF Code 3.2.13).
X	X	*Fixed gas detection suitable for all spaces and areas concerned are to be arranged* (ref. IGF Code 3.2.14). This requirement also implies that adequate ventilation is to be provided to protect personnel from an oxygen deficient atmosphere in the event of gas leakage.
X	X	*Fire detection, protection and extinction measures appropriate to the hazards concerned are to be provided* (ref. IGF Code 3.2.15).
X	X	*Commissioning, trials and maintenance of fuel systems and gas utilization machinery are to satisfy the goal in terms of safety, availability and reliability* (ref. IGF Code 3.2.16).
X	X	*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 (ref. IGF Code 3.2.17). Certified equipment and materials suitable for use are to be provided for gas systems.
X	X	*A single failure in a technical system or component are not to lead to an unsafe or unreliable situation* (ref. IGF Code 3.2.18).

Procedures are to be available to detail the criteria for safe routine, scheduled and unscheduled inspection and maintenance.

The required operational safety levels are to be achieved through appropriate crew training and certification.

Chapter 4 of the IGF Code contains the general requirements for the necessary assessments of the risks involved, to be carried out in order to eliminate or mitigate any adverse effect to the persons on board, the environment or the ship.

Coherently, the risk-based approach pertinent to the options FC-SHIP / ESSENTIAL or FC-SHIP / NON-ESSENTIAL is outlined in Section 2.

4 REQUIREMENTS FOR DIFFERENT FUELS

In general FC fuels systems are to be designed, installed, tested and maintained under the provisions of SOLAS or subsidiary IMO Codes.

In all instances where the applicable Rules and Regulations do not address adequately novel design features, the provisions of Section 1 of FC-SHIPS are to be supplemented by the application of a risk-based approach - see Section 2.

5 SHIP ARRANGEMENT – LOCATION, SEPARATION AND SEGREGATION OF SPACES

The ship general arrangement and machinery arrangement are to be defined to ensure that the goal and the functional Requirements listed above are complied with.

The safety goas are pursued with a correct ship arrangement, to provide for safe location, space arrangements and mechanical protection of FC power generation equipment, FC fuel storage systems, FC fuel supply equipment and FC refuelling systems.

The arrangement and location of spaces for FC gas fuel storage, distribution, processing and use are to be designed to minimize the number and extent of hazardous areas.

The Functional requirements listed in chapter 5.2 of the IGF Code relevant to LNG systems are fully applicable also to FC-SHIPS, in particular:

5.2.1.1 the FC fuel tank(s) location to minimize the probability for the tank(s) to be damaged following a collision or grounding;

5.2.1.2 fuel containment systems, fuel piping and gas release to a safe location in the open air;

5.2.1.3 containment of toxic gases;

5.2.1.4 fuel piping protection against mechanical damage;

5.2.1.5 the propulsion and fuel supply system arrangement to prevent any unacceptable loss of power;

5.2.1.6 minimization of the probability of a gas explosion in a machinery space with gas or low-flashpoint fuelled FC systems.

In this context, all the following requirements of the IGF Code chapters relevant to LNG systems are fully applicable to FC-SHIPS:
5.3 Regulations – General,
5.4 Machinery space concepts,
5.5 Regulations for gas safe machinery space,
5.6 Regulations for ESD-protected machinery spaces,
5.7 Regulations for location and protection of fuel piping,
5.8 Regulations for fuel preparation room design
5.11 Regulations for arrangement of entrances and other openings in enclosed spaces
5.12 Regulations for airlocks

Moreover:
- The geometrical shape of FC spaces is to be as simple as possible.
- FC spaces where hydrogen may be present are to be arranged with a smooth ceiling sloping up towards the ventilation outlet, without obstructing structures where explosive mixtures could accumulate. Support structures (e.g. girders, stiffeners) are to be facing outwards the spaces. Thin plate ceilings covering the support structures under the deck plating are not to be accepted.
- In general, the installation of FC systems in conventional machinery spaces is not to be permitted. In any case the segregation of FC spaces is to meet the requirements of the IGF Code listed above, to provide a suitable form of enclosure for the FC components containing / transferring FC fuel.
- The installation spaces of FC stacks and directly associated components are to be arranged outside of accommodation, service and machinery spaces and control rooms, and are to be separated from such spaces by means of a cofferdam, or A-60 rated bulkheads.

- Tank rooms are to be separated from the spaces containing FC power system components.
- Tank room boundaries is to be gas-tight.
- Tank rooms are not to be located adjacent to machinery spaces of category A. If the separation is by means of a cofferdam, this is to be at least 900mm wide and additional insulation to A-60 rating is to be fitted on the machinery space side.
- Access to all components of the FC installation is to be possible for survey.

For any new or altered concept / arrangement / configuration - e.g. retrofitting of a FC system on an existing ship - a risk analysis are to be carried out as outlined in Section 2, to identify the hazards, failure modes and consequences associated with design, operation and maintenance of FC installation on board.

6 SYSTEM DESIGN AND CONFIGURATION

6.1 MATERIALS – GENERAL

Goal

With ref. to chapter 7.1.1 of the IGF Code, the goal of this item is to ensure the safe handling of FC fuel, under all operating conditions, to minimize the risk to the ship, personnel and to the environment, having regard to the nature of the products involved.

Functional requirements

All FC power system equipment and components are to comply with manufacturer specifications, and are to be suitable for the service life-cycle with the range of process fluids and conditions expected during both normal operation and possible fault management operations.

Materials, in general, are to be in accordance with recognized standards.

Materials used in gas tanks, gas piping, process pressure vessels and other components in contact with gaseous fuels (hydrocarbon and hydrogen) covered by the IGC Code and IGF Code are to be in compliance with their relevant provisions.

The use of materials not covered by the IGC Code and IGF Code is to be specially evaluated by the Society.

All components in contact with hydrogen are to be made of materials compatible with this element, in particular with respect to embrittlement and hydrogen chemical reactions.

Information on material suitability and compatibility with hydrogen are contained in the International Standards (ISO, IEC or other equivalent) – see Sec 1, [1.10] above for reference.

Austenitic stainless steel – such as 304, 316, 304L and 316L – is to be used for materials in contact with hydrogen. Other materials compatible for storage and transport of hydrogen may be approved after special consideration and/or testing, subject to the submission of the relevant documentation.

When hydrogen is present as compressed gas, its temperature in normal operating conditions is considered to remain in a range between -40°C and +85°C and therefore the normal operating temperature range for materials used in hydrogen components is to be at least the same.

Different temperature ranges may be approved after special consideration and/or testing.

Materials having a melting point below 925°C are not to be used for piping outside the FC gas tanks (ref. chapter 7.4.1.2 of the IGF Code), with a possible exception for short lengths of pipes attached to, or in the close proximity of, the FC gas tanks. In such case the low melting point materials are to be protected by A-60 rating insulation.

Metallic materials for fuel containment and piping systems are to comply with the minimum regulations given in the following Tables of chapter 7.4.1 of the IGF Code:
Table 7.1: Plates, pipes (seamless and welded), sections and forgings for fuel tanks and process pressure vessels for design temperatures not lower than 0°C.
Table 7.2: Plates, sections and forgings for fuel tanks, secondary barriers and process pressure vessels for design temperatures below 0°C and down to minus 55°C.
Table 7.3: Plates, sections and forgings for fuel tanks, secondary barriers and process pressure vessels for design temperatures below minus 55°C and down to minus 165°C.
Table 7.4: Pipes (seamless and welded), forgings and castings for fuel and process piping for design temperatures below 0°C and down to minus 165°C.
Table 7.5: Plates and sections for hull structures required by chapter 6.4.13.1.1.2 of IGF Code

Additional requirements for materials are provided in the specific items of FC-SHIPS (e.g. Piping, Gas fuel storage and supply…).

6.2 PIPING - DESIGN AND ARRANGEMENT

All provisions of chapter 7.3.1 of the IGF Code *Regulations for general pipe design - General* are fully applicable to FC-SHIPS and are to complied with.

With ref to chapter 7.3.1.2 of the IGF Code - electrical bonding - this may be also achieved specifying a pipe material with sufficient conductivity, or limiting the gas flow velocity to values below which electrostatic charge does not accumulate.

Piping relying on a protective system to eliminate electrostatic discharge (grounding wire or braid) is not to be used in a Zone 0 location. Metal braid coverings, or conductive wires within non-metallic piping wall, may increase the risk of electrostatic discharge if they become disconnected from their bonding conductor.

In Zone 1 and 2 areas, such conductors are to be mechanically secured with positive means.

All provisions of IGF Code chapters:

7.3.2 *Wall thickness*,

7.3.3 *Design conditions*,

7.3.4 *Allowable stress*,

7.3.5 *Flexibility of piping*,

7.3.6 *Piping fabrication and joining details*

are fully applicable to FC-SHIPS and are to complied with.

FC fuel pipes in spaces made gas safe are not to include expansion elements, bellows or other pipe components with poorer strength, fatigue or leakage properties than the fully welded pipe.

With reference to the provisions of IGF Code chapter 7.3.6.4.1.3 *Direct connections*: Screwed couplings complying with recognized standards are only to be used for accessory lines and instrumentation lines with external diameters of 25 mm or less.

In any case, screw fittings are to be in accordance with standards approved by the Society, and the use of screwed connections will be specially evaluated by the Society.

Heat treatment post-welding is to be required for all butt welds of pipes made of carbon, carbon-manganese and low-alloy steels. The Society may waive the recommendation for thermal stress relieving of pipes having wall thickness less than 10 mm in relation to the design temperature and pressure of the piping system.

Gas pipes are preferably to be located as specified in chapter 5.3.3 of the IGF Code for gas fuel tanks, but in no case less than 0.8 m from the shell plating or aft terminal of the ship.

In accordance with chapter 5.7.2 of the IGF Code, FC gas fuel piping is not to be led directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention.

Gas fuel piping may pass through or extend into other spaces provided that their position and layout are duly considered in the Risk-based approach, as defined in Section 2.

An arrangement for purging FC fuel bunkering lines and supply lines with nitrogen are to be provided.

If a fuel gas contains heavier components that may condensate in the system, knock out drums or equivalent means for collecting the liquid are to be fitted.

Piping system configuration.

The presence of FC fuel release sources in a FC space will decide if it is regarded as a hazardous or non-hazardous space.

Two alternatives can be considered to make non-hazardous a FC space containing FC fuel piping inside. In synthesis:

- All FC fuel pipes are to be enclosed in a gastight double enclosure fulfilling the requirements of chapters 5.5 and 9.6 of the IGF Code. In general, hydrogen pipes are to be located in well ventilated spaces, and are to be fully welded, as far as practicable, depending on their diameter (e.g. less than 25mm). For hydrogen pipes, the double wall principle used to make a surrounding space non-hazardous, is only acceptable pending special consideration from the Society.
- All FC fuel pipes that are not inside a double enclosure are to be fully welded and the ventilation rate in the FC is to be sufficient to avoid gas concentration in the flammable range in all leakage scenarios, including pipe rupture. In addition, the FC space is to be fitted with gas detection and with an automatic shutdown system of the fuel supply. Hydrogen valves are to be leakage tested with hydrogen. In general, valves in the FC piping are to be leakage tested for the FC fuel used. However, for FC fuels different from hydrogen, normal hydrostatic pressure testing with water together with a tightness test with an inert gas as part of the product certification may be considered sufficient. In a space kept gas safe in this way, compensators or other pipe components with strength, fatigue or leakage properties poorer than the fully welded pipe is not to be accepted in FC fuel piping.

Where explosive, flammable, or toxic fluids are contained in the piping, appropriate precautions are to be taken in the design and marking of sampling and take-off points.

6.3 FUEL CELLS FUEL INSTALLATION

6.3.1 CONTAINMENT SYSTEM

The goal and the functional requirements of this item are coherent with those identified in chapters 6.1 and 6.2 of the IGF Code:

Goal

To provide that the FC storage and containment is adequate so as to minimize the risk to personnel, the ship and the environment to a level that is equivalent to a conventional oil fuelled ship.

Functional requirements

.1 the FC fuel containment system is to be so designed that a leak from the FC tank or its connections does not endanger the ship, persons on board or the environment. Potential dangers to be avoided include:

.1 exposure of ship materials to temperatures below acceptable limits;

.2 flammable fuels spreading to locations with ignition sources;

.3 toxicity potential and risk of oxygen deficiency due to fuels and inert gases;

.4 restriction of access to muster stations, escape routes and life-saving appliances (LSA); and

.5 reductions in availability of LSA.

.2 the pressure and temperature in the FC fuel tank are to be kept within the design limits of the containment system and possible carriage requirements of the FC fuel;

.3 the FC fuel containment arrangement is to be so designed that safety actions after any gas leakage do not lead to an unacceptable loss of power; and

.4 if portable tanks are used for FC fuel storage, the design of the FC fuel containment system is to be equivalent to permanent installed tanks and is to comply with the requirements of chapter 6.5 of the IGF Code *Regulations for portable liquefied gas fuel tanks.*

FC fuel storage

If LNG is selected as primary FC fuel, and hydrogen-rich gas for the FC modules is obtained as the result of a reforming / chemical process, primary fuel tanks will be covered by existing fuel specific parts in the IGF Code and the provisions of chapter 6 *Fuel Containment System*, including those of chapter 6.4 of the IGF Code are to apply.

If other primary FC fuels are selected (e.g. methanol), and hydrogen-rich gas for the FC modules is obtained as the result of a reforming / chemical process, the provisions contained in Sec 1, [4] are to apply.

If the FC fuel is not covered by the IGF Code provisions, an alternative design is to always be carried out.

Buffer tanks or intermediate tanks between the reformer and the FC are not considered as components of the primary FC fuel storage, but as a item of the FC fuel supply system – see Sec 1, [6.3.2].

The use of hydrogen as primary FC fuel is to always be specially evaluated by the Society, following a risk-based approach as outlined in Section 2 of FC-SHIPS.

In case of liquid hydrogen storage, the inner pressure vessel must be designed to operate at very low temperature. All piping and components in contact with liquefied hydrogen are also to be designed to withstand these temperatures.

A comprehensive risk-based approach with evaluation of the possible failure modes is always required in case of liquid hydrogen installations.

The risks related to the storage of hydrogen as fuel with respect to collision and potential storage under accommodation spaces are to be specifically evaluated.

The functional requirements listed in chapter 5.2 of the IGF Code relevant to the *Location of gas storage tanks* and *Low flashpoint fuel storage systems*, are fully applicable also to FC-SHIPS.
The Regulations contained in chapter 6.6 - all subparagraphs - of the IGF Code are applicable in case of compressed gas installations.

If the FC fuel storage tanks are to be used for compressed hydrogen, these are to be certified and approved by the Society and the Flag Administration. The design and construction are to comply with relevant Recognised Codes and Standards for hydrogen storage. The applicability of Codes and Standards to sea going containment system is to be demonstrated, subject to special consideration by the Society.

With ref. to chapter 6.6.4 of the IGF Code, storage of compressed and liquefied gases on open deck is preferred. Storage in enclosed spaces is normally not acceptable, but may be permitted after special consideration and approval by the Society and the Flag Administration, when in compliance with the provisions Sec 1, [5] and Chapters 5.3, 6.3.4, 6.3.5 and 6.3.6 of the IGF Code and with the following additional provisions:

.1 adequate means are provided to depressurize and inert the tank in case of a fire which can affect the hydrogen storage system;

.2 all surfaces within such enclosed spaces containing the compressed hydrogen storage system are provided with suitable thermal protection against any high-pressure gas leakage and resulting condensation unless the bulkheads are designed for the lowest temperature that can result from gas leakage expansion;

.3 a fixed fire-extinguishing system is installed in the enclosed spaces containing the compressed hydrogen storage system. Special consideration is to be given to the extinguishing of jet-fires.

6.3.2 FUEL SUPPLY SYSTEM TO CONSUMERS

General

This item contains the requirements for the FC fuel supply system, from the primary FC fuel tanks to the FC modules / stacks within FC spaces.

The FC fuel supply depends on the selected FC technology. The manufacturer specifications for the use and quality of FC fuels are to be complied with.

If hydrogen is selected as primary FC fuel, the piping system and the relevant valves, fittings and components are to comply with the requirements of the previous items and the applicable recognized international standards for hydrogen handling.

If other liquid or gaseous fuels are used as primary FC fuels, then a fuel reformer may be required – see Sec 1, [6.3.3].

The FC fuel supply system is to comply with the provisions of chapter 9 of the IGF Code. More specifically.

The goal and the functional Requirements are those of chapters 9.1 and 9.2 of the IGF Code respectively.

Regulations on redundancy of fuel supply – all provisions of chapter 9.3 of the IGF Code are applicable to FC installations for which the option FC-SHIPS ESSENTIAL is selected.

Regulations on safety functions of gas supply system – all provisions of chapter 9.4 of the IGF Code, all sub-paragraphs, are applicable.

In addition to the provisions of Sec 1, [9.4.2], the manually operated stop valve and the automatically operated master gas fuel valve coupled in series, or the combined manually and automatically operated valve, are to be situated in the part of the piping that is outside the machinery space containing gas consumers, and in any case before the reformer, if installed.

With ref. to Sec 1, [9.4.9], on single-FC power installations and multi-FC installations, a separate master valve is to be provided for each FC installation, and the master gas fuel valve and the double block and bleed valve functions can be combined.

The temperature of installations along the FC fuel supply system, and within the FC space, is not to exceed the self-ignition temperature for the FC fuel used.

If heating media for FC liquid fuel, FC liquefied-gas evaporators or FC gas preheaters are needed, which are routed back into spaces located outside the area of the FC gas treatment plant, these have to pass through degassing containers / treatment located within the hazardous area.

Regulations for fuel distribution outside of machinery space – all provisions of chapter 9.5 of the IGF Code, all sub-paragraphs, are applicable.

Routing of hydrogen pipes outside of machinery spaces is normally not accepted, however it can be considered only if these spaces are defined as gas hazardous, i.e. all equipment located inside are spark proof and certified safe for hydrogen atmosphere. Such spaces are required to have a ventilation system and ventilation rate as for FC fuel spaces with open hydrogen pipes, and the spaces are to have a simple geometrical shape to prevent any accumulation of explosive gases.

Gas pipes located in open air, are to be located or protected to prevent damage by accidental mechanical impact.

High-pressure gas pipes and components located outside the FC spaces are to be installed and protected to minimize the risk of injury to personnel in case of rupture.

Regulations for FC fuel supply to consumers in gas-safe machinery spaces – all provisions of chapter 9.6 of the IGF Code are applicable. The outer pipe or duct is to be tightness tested.

Regulations for FC gas fuel supply to consumers in ESD-protected machinery spaces – all provisions of chapter 9.7 of the IGF Code are applicable.

Regulations for the design of ventilated duct, outer pipe against inner pipe gas leakage – all provisions of chapter 9.8 of the IGF Code are applicable.

Regulations for compressors and pumps – all provisions of chapter 9.9 of the IGF Code are applicable.
Moreover:

- Arrangements are to be made to ensure that under no circumstances untreated liquefied gas is introduced in the FC modules / stacks - ref. to chapter 9.9.3 of the IGF Code.
- Compressor rooms, if arranged, are to be preferably located above weather deck level, unless especially approved by the Society.

Compressors:

- are to be manually switched-off from a permanently accessible point outside their installation space (e.g. in cargo control room of cargo ships, wheelhouse / safety centre, engine control room, fire control station).
- are to be stopped automatically if the outlet pressure is too high or the suction pressure is too low
- are not to be restarted automatically before a manual reset
- if compressors are driven by shafting passing through a bulkhead or deck, the bulkhead penetration is to be of gastight type.

Regulation for FC fuel filters - Filters used to prevent FC fuel contamination (e.g. solid particles - which could also include oxygen):

- are to be in quantity and location as per FC system manufacturer recommendations;

- are to be accessible for cleaning in accordance with periodical / programmed maintenance;
- are not to be cleaned by back-flushing the system;
- are preferably to be made of non-metallic components to prevent accumulation of static electric charge; bonding and grounding are to be designed accordingly.

Regulation for Purging
An inert gas subsystem is required for purging operations.

FC systems are to be purged with an inert gas to remove air before admitting FC gas fuel into the component (e.g. FC supply piping, reformer, FC modules…) and the component is to be purged of FC gas fuel before opening it to air.

FC components containing hydrogen are to be purged with an inert gas before and after operation.

Compatibility of the inert gas with the characteristics of the gas to be purged is to be considered.

When cryogenic gases are used, the inert gas is to have a melting point lower than FC gas fuel, to prevent freezing.

The purging technique is to be submitted to the Society for approval and is to include all essential design parameters such as flowrate, duration, mixing / dilution of the gases.

The purged gas is to be vented to an open outdoor area, in compliance with the requirement of Sec 1, [6.4].

Other

Pressure reduction devices and relief valves are to be so designed that a failure cannot endanger the downstream components, taking into account the design pressure rating and the maximum allowable working pressure of the system.

With ref. to chapter 9.9.2.2 of the IGF Code *Shipboard vibrations and accelerations*, special consideration is to be given to possible fatigue problem in the FC fuel piping systems due to vibration caused by the FC fuel compressor, by unbalanced forces, or by resonance in the FC piping systems. Specific calculations may be required by the Society to verify that vibration problems are avoided.

6.3.3 FUEL REFORMER

Fuel reformer is the arrangement of all related fuel reforming equipment for processing gaseous or liquid fuels to reformed fuel - i.e. hydrogen-rich gases - for use in the FC.

Evaporation of liquefied gases from the primary fuel tanks is not to be considered as a part of the fuel reforming process.

The fuel reformer, if installed, is to be located between the primary fuel tanks and the FC modules / stacks.

The reforming equipment may be an integrated part of the FC assembly or be arranged as an independent unit, with reformed fuel piping connected to the FC.

The reformed fuel consists of hydrogen-rich gases, defined also as Synthesis gas or Syngas, i.e. a gaseous substance that can directly interact with the anode of a FC without any further need of physical or chemical transformation. In this context, Synthesis gas includes also pure hydrogen, which can directly interact with the FC modules / stacks.

Buffer tanks or intermediate tanks between the fuel reformer and the FC may be required for the storage of reformed fuels, depending on the technology selected for the FC system.

Several different FC technologies are available on the market, such as:

- alkaline fuel cell (AFC),
- polymer exchange membrane fuel cell (PEMFC),
- high temperature PEMFC (HT-PEMFC), liquid cooled
- direct methanol fuel cell (DMFC),
- phosphoric acid fuel cell (PAFC),
- molten carbonate fuel cell (MCFC),
- solid oxide fuel cell (SOFC).

The choice of these, or other FC technologies, depends on a combination of their merits and their potential for commercial application.

PEMFC, HT-PEMFC and SOFC are the most likely FC technologies to be used for marine applications.

In general:

- PEMFC operation requires pure hydrogen (platinum catalyst is sensitive to poisoning), and the operating temperature is low (50-100°C). The main safety concerns are related to the use and storage of hydrogen on board. Energy conversion with a PEMFC, from hydrogen to electricity, would essentially result in water as the only emission and low quality heat. PEMFC are very sensitive to impurities in the hydrogen (mainly Sulphur and CO). Hydrocarbons can be used as a fuel for PEMFC, using a separate steam reforming and subsequent water-gas-shift system to make hydrogen of the necessary purity. CO_2 and low levels of NOX are emitted if hydrocarbons are used as fuel.
- HT-PEMFC have a reduced sensitivity towards impurities – eliminating the need for a clean-up reactor after the reformer - and water is only present in gaseous phase as a result of the higher temperature, up to 200°C.
- SOFC are highly efficient, with very high operating temperatures (500-1000°C). The FC is flexible towards different fuels, with the reforming from

primary fuels (LNG, methanol/ethanol and hydrocarbons as low Sulphur diesel) to syngas (hydrogen and CO) taking place internally within the FC. The high temperature implies a detailed safety assessment, including the environmental implications (when using hydrocarbon fuels, there are CO_2 and some NOx emissions).

When fuel reforming systems are needed to produce hydrogen-rich reformed fuel gases for use in the FC, additional safety considerations may be required to account for their constituent elements, chemical and physical properties, such as toxicity, combustibility, corrosion resistance, temperature and pressure operating conditions.

Chemical reactions, such as those taking place during fuel reforming and within the FC, are to be continuously monitored, e.g. by means of temperature, pressure or voltage monitoring systems.

If limit values determined for the control of the reforming process - e.g. temperature, pressure, voltage - are exceeded and may lead to hazardous situations, the FC power system are to be automatically shut down and interlocked by an independent protective device. See also Sec 1, [11].

The requirement for purity of the FC fuel depends on the selected FC technology. This requirement has an implication on the FC performance and the life-cycle of the FC stacks (i.e. replacement frequency). The manufacturer specifications and operational instructions of the reformer and the FC stacks are to be complied with.

In any case, hydrogen will be present in the close vicinity of the FC, being an active substance in the FC. Hydrogen will be present through all the process lines between the reforming unit and the FC, meaning that hydrogen safety concerns will always be present in form of possible leakage (from piping, system components and the FC itself) and ignition hazards (e.g. static electricity generated by ventilation systems within double wall arrangements of hydrogen pipes).

Consequently:
- Reformers have to comply with the requirements of Sec 1, [6.3.2].
- Reformers cannot be located outside machinery spaces.

The risk-based approach for FC reformers is to include an assessment of the operational criteria, including but not limited to:
- FC specific fuel properties
- possible water contamination with dissolved hydrogen or other chemical impurities
- power and heat balance
- temperature rise as a consequence of fuel flow failure or liquid cooling system failure and resulting fire hazards.

6.3.4 BUNKERING SYSTEM

The goal and the functional requirements are those of chapters 8.1 and 8.2 of the IGF Code respectively.

The bunkering station is to be physically separated and structurally shielded from accommodation, cargo / working deck and control stations.

The provisions of the following IGF Code chapters are also applicable:

8.3 Regulations for bunkering station.
- 8.3.1 General: bunkering station location; connections and piping; safe management of any spilled fuel; liquid contents removal from bunker lines; low temperature steel shielding (when applicable).
- 8.3.2 Ships' fuel hoses.

8.4 Regulations for manifold.

8.5 Regulations for bunkering system.
- 8.5.1 Inert gas arrangement for purging fuel bunkering lines.
- 8.5.2 Gas discharge prevention.
- 8.5.3 Stop valve and a remote operated shutdown valve operation
- 8.5.4 Fuel drainage from bunkering pipes upon completion of operation.
- 8.5.5 Bunkering lines inerting and gas freeing.
- 8.5.6 Bunkering lines cross-over arrangement.
- 8.5.7 Automatic and manual ESD means of communication to the bunkering source.
- 8.5.8 alarm and closure of the remote operated valve.

Moreover:

Control of the bunkering is to be possible from a safe location with respect to bunkering operations. At this location monitoring and indication of tank pressure, tank level, tank overfill and automatic shutdown are to be possible.

An alarm is to sound at the bunkering control location if:
- the ventilation in the ducting around the FC fuel bunkering lines stops;
- gas is detected in the ducting around the bunkering lines.

Liquid fuel drip trays may be required, depending on the selected fuel, to be fitted below the bunkering connections and/or anywhere leakage may occur.

The drip trays are to be made of austenitic stainless steel and be drained overboard into the sea by a pipe (which could be temporarily fitted, just for bunkering operations).

Means to provide electrical continuity with the refilling facilities throughout the bunkering process are to be provided before bunkering is permitted.

Risk studies and a qualification process are needed to identify and assess the most suitable bunkering procedures.

The risk-analysis are to take into account the influence of different fuel properties on the definition of hazardous zones and the minimum safety distances.

For bunkering of liquid hydrogen or gaseous hydrogen, ref. can to be made to land based standards, such as:

- ISO 17268:2012 Gaseous hydrogen land vehicle refuelling connection devices
- ISO/TS 19880-1:2016 Gaseous hydrogen – Fuelling stations – Part 1: General requirements
- SAE J2601 - SAE (Society of Automotive Engineers) Protocol for fuelling road vehicles.

6.4 VENTILATION SYSTEMS

Goal

The goal of this item is to provide for the ventilation required for safe operation of gas-fuelled FC installations.

Functional requirements

The functional requirements of this item are related to the functional requirements contained in Sec 1, [3].

General

Spaces containing FC installations are to be equipped with an independently driven forced ventilation and extraction system.

Any ducting used for the ventilation of hazardous spaces are to be separate from any other ducting used for the ventilation of non-hazardous spaces.

The ventilation is to function at all temperatures and environmental conditions the ship will be operating in - ref. chapter 13.3.1 of IGF Code.

Electric motors for ventilation fans are not to be located in ventilation ducts for hazardous spaces unless the motors are certified for the same hazard zone as the space served - ref. chapter 13.3.2 of IGF Code.

Electric fan motors are not to be located in ventilation ducts serving spaces containing hydrogen installations. Ventilation units are to have a safe bonding to the hull.

The design and the construction materials of ventilation fans serving spaces containing FC gas sources are to comply with the provisions of chapter 13.3.3 of the IGF Code.

Ventilation systems required to avoid any gas accumulation or explosive gas mixture pockets, are to consist of independent fans, each of sufficient capacity - ref. chapter 13.3.4 of IGF Code.

Air inlets for hazardous enclosed spaces are to be taken from areas which, in the absence of the considered inlet, would be non-hazardous. Air inlets to non-hazardous enclosed spaces are to be taken from non-hazardous areas, at least 1.5 m away from the boundaries of any hazardous area. Where the inlet duct passes through a more hazardous space, the duct is to be gas-tight and have over-pressure relative to this space - ref. chapter 13.3.5 of IGF Code.

Air outlets from non-hazardous spaces are to be located outside hazardous areas - ref. chapter 13.3.6 of IGF Code.

Air outlets from hazardous enclosed 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 - ref. chapter 13.3.7 of IGF Code.

The required capacity of the ventilation plant is to normally be based on the total volume of the room. An increase in required ventilation capacity may be necessary for rooms having a complicated shape and layout - ref. chapter 13.3.8 of IGF Code.

Ventilation fans may be either variable speed - changing speed automatically - or dual-speed, or fixed speed, depending on operational requirements and FC power load variations within the served spaces.

The required pressure balance in the FC ventilated rooms is to be maintained automatically by varying the output or the number of ventilation fans in operation.

The ventilation system is to be designed to limit the mean temperature rise above ambient atmospheric temperature to 10°C in all FC installation spaces, with all FC modules in operation and with an outside temperature of 35°C.

Spaces above reformers - or any other FC heated component - up to the underside of the deck above, are to be specially considered to ensure the effectiveness of the cooling and prevent heat radiating to the spaces above.

The final number and characteristics of the supply and exhaust ventilation fans and the relevant calculations are to be submitted for approval.

Air distribution is to be through stainless steel grilles with anti-ratting meshes 10 x 10 x 1.5 mm. Non-structural inlet ducts, internal grids and diffusers are to be made of AISI 316 L stainless steel.

External air supply inlets and exhaust outlets are to be fitted with louvres, electrically isolated from the ship's structure. Inlets and exhaust outlets are to be fitted with spray eliminators made of 316L stainless steel to prevent the entry of rain and spray and protect the ducting, dampers and equipment connected to the inlet. The air velocity through the inlet louvers and the design of the louvers are to be defined to prevent rain and spray intake.

The spray eliminators, together with any coalesce system, are to be designed to achieve 99% spray removal, with a water removal capacity not less than 18 litres/m^2/min.

Non-hazardous spaces with entry openings to an external hazardous area are to be arranged with an airlock and be maintained at overpressure relative to the external hazardous area.

The overpressure ventilation is to be arranged according to the provisions of chapter 13.3.9 of IGF Code:

.1 During initial start-up or after loss of overpressure ventilation, before energizing any electrical installations not certified safe for the space in the absence of pressurization, it is to be required to:

- proceed with purging (at least 5 air changes) or confirm by measurements that the space is non-hazardous; and
- pressurize the space.

.2 Operation of the overpressure ventilation is to be monitored and, in the event of failure of the overpressure ventilation:

- an audible and visual alarm are to be given at a permanently manned location outside the hazardous areas; and
- if overpressure cannot be immediately restored, automatic or programmed disconnection of electrical installations is to be required according to a recognized standard (e.g. IEC 60092-502:1999 Electrical Installations in Ships – Tankers – Special Features, table 5) as well as the automatic shut-off of the FC gas supply. Certified flameproof lighting, may have a separate switch-off circuit.

Non-hazardous spaces with entry openings to a hazardous enclosed space are to be arranged with an airlock and the hazardous space are to be maintained at under pressure relative to the non-hazardous space - ref. chapter 13.3.10 of IGF Code. Operation of the extraction ventilation in the hazardous space is to be monitored and in the event of failure of the extraction ventilation:

- an audible and visual alarm are to be given at a permanently manned location outside the hazardous areas; and
- if the lower pressure cannot be immediately restored, automatic or programmed disconnection of electrical installations is to be required according to a recognized standard as well as the automatic shut-off of the FC gas supply. Certified flameproof lighting may have a separate switch-off circuit.

Ventilation suctions in spaces containing FC fuel heavier than air (e.g. propane, butane…) are to be from the lowest points of the served space.

The ventilation systems are to be controlled from outside the served spaces.

The ventilation system is to be started before the FC system is started - to ensure a safe operational conditions and safe access of the service personnel into the ventilated spaces. Suitable warning notices are to be placed outside the ventilated spaces, and in a visible position near the control position.

In spaces containing hydrogen, the ventilation rate is to be sufficient to avoid gas concentration within the flammable range in all leakage scenarios, including pipe rupture.

This is also applicable to spaces containing fully welded hydrogen pipes.

The geometry of ventilation ducts from spaces containing hydrogen piping or other hydrogen release sources, is to be simple, possibly vertical and steadily ascending, to minimize the risk of gas accumulation.

Spaces containing FC fuel release sources are to be monitored by gas detection systems.

The exhaust gas content in the extracted air is also to be monitored.

Permanently installed gas detectors, suitable for all types of flammable gases which may be present, are to be fitted where gas may accumulate - i.e. in FC spaces and in the ventilation system - for the detection of any FC fuel gas leakage.

Regulations for FC tank connection space

The FC tank connection space is to be provided with an effective mechanical forced ventilation system of extraction type. A ventilation capacity of at least 30 air changes per hour is to be provided - ref. chapter 13.4.1 of IGF Code. The rate of air changes may be reduced if other adequate means of explosion protection are installed, but is to anyway be sufficient to avoid gas concentration in the flammable range in all leakage scenarios, including pipe rupture. The ventilation rate is to be calculated in accordance with a recognized international standard. The equivalence of alternative installations is to be demonstrated by a risk assessment.

Approved automatic fail-safe fire / shut-off dampers are to be fitted in the ventilation trunk serving the FC tank connection space - ref. chapter 13.4.2 of IGF Code. Air inlets and outlets are be provided with self-operating electrically actuated fire and shut-off dampers, interlocked with the fan starting sequence and the FC system starting sequence.

Suitable protective screens are to be installed in way of ventilation duct openings.

Fire / shut-off dampers are to be made of 316 L stainless steel with self-lubricated bronze bearings and remote electrical control. All dampers are to be installed to enable access for inspection and maintenance.

Regulations for FC machinery spaces

The ventilation system for FC machinery spaces containing gas-fuelled FC consumers is to be independent of all other ventilation systems - ref. chapter 13.5.1 of IGF Code.

ESD protected FC machinery spaces are to have ventilation with a capacity of at least 30 air changes per hour - ref. chapter 13.5.2 of IGF Code. The ventilation system is to ensure a good air circulation in all spaces, and in particular ensure that any formation of gas pockets in the room is detected. As an alternative, arrangements whereby under normal operation the FC machinery spaces are ventilated with at least 15 air changes per hour is acceptable provided that, if gas is detected in the FC machinery space, the number of air changes will automatically be increased to 30 per hour.

To comply with the FC SHIP ESSENTIAL option, for ESD protected FC machinery spaces, the ventilation arrangements are to provide sufficient redundancy to ensure a high level of ventilation availability (see also IEC 60079-10-1 standard).

In addition to the provisions of chapter 13.5.3 of IGF Code, the number and power of the ventilation fans are to be defined in accordance with redundancy criteria, to ensure that the ventilation capacity is maintained at 100% in case of a single failure in the ventilation system.

When the option FC SHIP ESSENTIAL is selected, in addition to the provisions of chapter 13.5.4 of IGF Code, the number and power of the ventilation fans for ESD protected FC system rooms and for double pipe ventilation systems for gas safe FC system rooms are to be such that the capacity is maintained at 100% in case of a single failure in the ventilation system.

Regulations for FC fuel preparation room and spaces containing the reformer

FC fuel preparation rooms and spaces containing the reformer, are to be fitted with effective mechanical ventilation system of the underpressure type, providing a ventilation capacity of at least 30 air changes per hour - ref. chapter 13.6.1 of IGF Code.

When the option FC SHIP ESSENTIAL is selected, in addition to the provisions of chapter 13.6.2 of IGF Code, the number and power of the ventilation fans are to be such that the capacity is maintained at 100% in case of a single failure in the ventilation system.

Ventilation systems for fuel preparation rooms and spaces containing the reformer, are to be in operation when pumps or compressors are working - ref. chapter 13.6.3 of IGF Code.

Regulations for bunkering station

Bunkering stations which are not located on an open deck are to be suitably ventilated to ensure that any vapour being released during bunkering operations will be removed outside - ref. chapter 13.7 of IGF Code. If the natural ventilation is not sufficient, mechanical ventilation is to be provided in accordance with the risk assessment required by Section 2.

Regulations for ducts and double pipes containing FC fuel piping

The provisions of chapters 13.8.1 (not applicable to double pipes in the FC system room if the provisions of chapter 9.6.1.1 of the IGF Code are applicable), 13.8.2, 13.8.3, 13.8.4 of IGF Code are to be complied with.

7 FUEL CELLS POWER SYSTEM

7.1 GENERAL

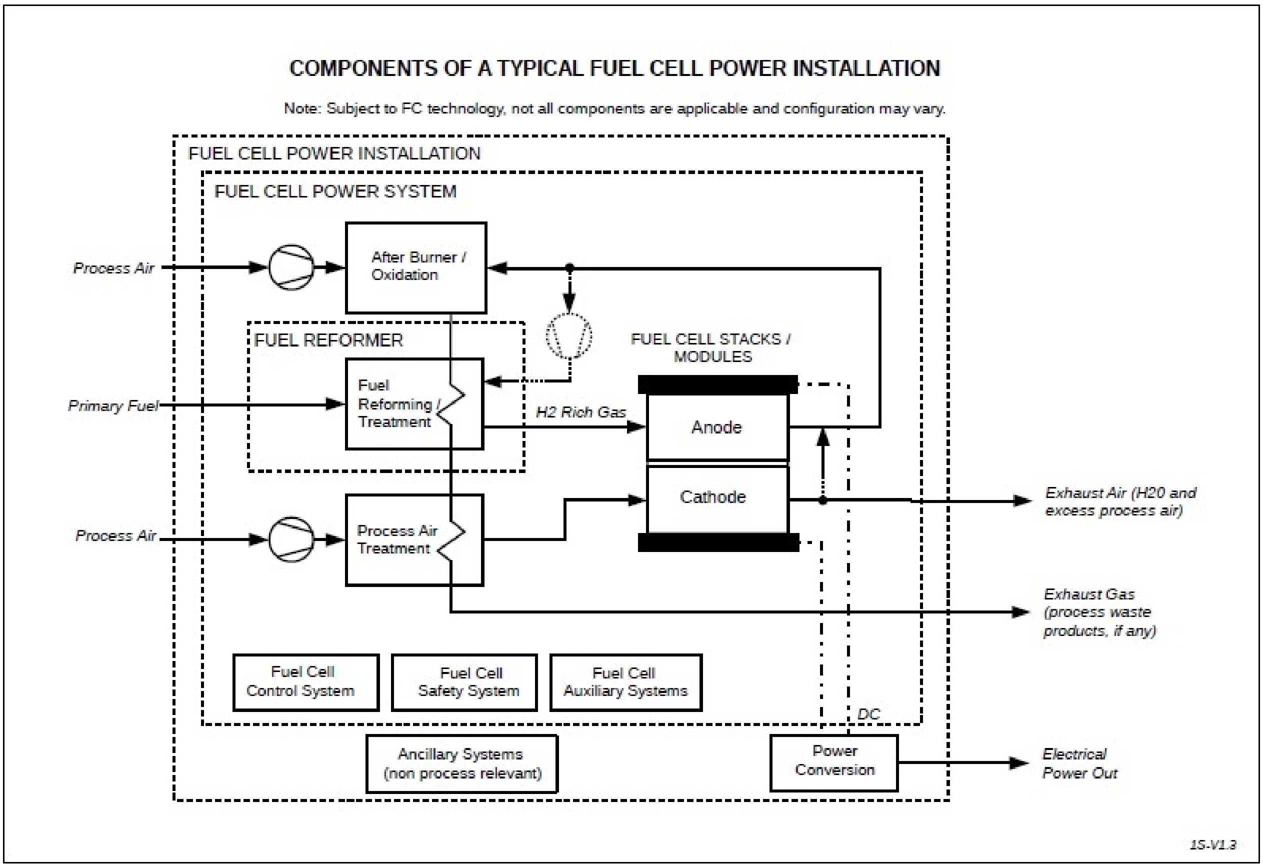
Goal

The goal of this item is to provide safe and reliable delivery of electrical / mechanical / thermal energy of FC installations.

Functional requirements

This item is related to functional requirements contained in Section 2.

Table 6: Components of a typical FC power installation



The risks related to the FC power systems depend on the selected FC technology (PEMFC, HT-PEMFC, SOFC…) and its use for marine applications.

The essential risk factor is the presence of hydrogen - or hydrogen-rich reformed fuels - as active substance in any FC.

Hydrogen will be present through all the process lines between the reforming unit and the FC modules / stacks, although these lines may be very short in case of integrated reformer and FC modules.

Hydrogen safety concerns will always be present in form of possible accumulation of un-burnt gaseous fuel, FC fuel over pressure due to ignited gas leaks and explosion hazards.

Additional safety concerns are the use of FC systems in a marine environment and the FC and reforming system operating temperature - depending on the selected technology.

The FC systems design and installation are to follow a suitable Technology Qualification Process, to demonstrate that they are fit for purpose throughout their expected life-cycle in the physical environmental conditions expected on board - e.g. temperature range, relative humidity, saline atmosphere, contaminants, dust, ship motions, hull deformations, vibrations, acceleration due to collision or allision, electromagnetic susceptibility, etc. - in accordance with the manufacturer requirements and applicable recognized international standards – see Sec 1, [1.10] for reference.

In the absence of system type-approval schemes for modular FC installations, the manufacturer standards and guidelines for interfaces and integration of FC modules / stacks with the associated ship equipment (FC auxiliary systems), are to be evaluate on a case-by-case basis by the Society, depending on the extension of “turn-key” supply of the FC modules.

Complete documentation of the FC modules is to be submitted for approval, including but not limited to: design criteria, system schematics, components layout, operational functionality, interface and connection with any waste heat recovery units and batteries – see also Table 1.

FC power systems are to be designed, installed, operated and maintained throughout their expected life-cycle following a risk-based approach - see Section 2.

The safety aspects concerning any possible release of hydrogen within the FC system is to be specifically considered, with reference to:

- Installation and use within a FC room of equipment not protected against explosion;
- Effectiveness of minimum ventilation rate and flow dynamics to avoid gas concentrations in the flammable range in all leakage scenarios within the FC compartment and double wall piping.
- Safety requirements for batteries used in the context of hydrogen FC systems.
- Critical scenarios of hydrogen ignition sources, fire and explosion behaviour and risk controlling measures.
- Components and material properties.
- Structural strength / resilience of bulkheads and decks to withstand explosions vs. use of explosion hatches or pressure release panels.

To evaluate possible leak from the FC system, CFD simulations may be required of FC gas release/dispersion - depending on the effects of ventilation in the room, gas detection measures and ESD times - in order to maintain hydrogen concentrations below flammability limits.

Moreover:

- The same type of environmental conditions requested for storage tanks supports and fixing elements (ref. chapter 6 of the IGF Code) are to be applied.
- The temperature ratings of FC power system components and materials is to be consistent with the maximum expected range of operational temperatures.
- The FC power system enclosure is to be designed to safely contain any leak of hazardous liquids used therein. The containment means are to have a capacity of 110 % of the maximum volume of fluid which may leak.
- All FC fuel containment components are to be protected against mechanical damage.
- All safety shutdown systems and components whose failure may result in any hazardous event identified by the risk-based approach, are to be certified and tested for their intended use.
- The FC power system is to comply, as a minimum, with the provisions of the IMO Code on noise levels on board ships (adopted by Resolution MSC.337(91) on 30 November 2012, mandatory under SOLAS Regulation II-1/3-12), supplemented by any other requested additional class notation, e.g. Tasneef Rules for the Classification of Ships -Part F - Chapter 6 - Comfort on Board (COMF), if applicable.

Injury prevention

Accessible parts of the FC power system are to have no sharp edges, no sharp angles, and no rough surfaces which are likely to cause injury.

The FC power system is to be designed and constructed to prevent slipping, tripping or falling.

Any moving part of the FC power system is to be designed, constructed and protected to avoid contacts which could cause injury.

Risk of injury caused by contact with, or proximity to, components at high temperatures is to be properly addressed.

7.2 PROCESS AIR SUPPLY AND TREATMENT FOR FC MODULES

See relevant provisions in Sec 1, [6.4].

The FC power modules manufacturer are to design and specify the required capacity of the process air supply -intake / exhaust, into / from the FC power unit cabinets - based on the chemical process and power of the FC installation.

The process air supply and treatment system design are to be specifically approved by the Society.

7.3 PROCESS AIR FOR AFTER BURNER / OXIDATION

In normal operational conditions, the FC oxidant processing system may release a mixtures of oxygen depleted gases. The further exhaust system (release to the atmosphere), or re-processing system of this exhaust mixture (e.g. for preheating of the reformer, or treatment of process air) are to be designed and installed to prevent anoxia hazards for the personnel.

In emergency conditions, e.g. gas tightness failure and accidental release in the FC stack, the oxidant

processing system exhaust may contain a flammable / explosive gaseous mixture.

The provision of Sec 1, [6.4] is to be applicable to the oxidant processing exhaust system and is to be specifically approved by the Society.

7.4 PRESSURE EQUIPMENT AND PIPING

FC power systems containing high pressure fluid are to comply with the applicable standards and with the provisions for FC piping of Sec 1, [6.2].

A pressure monitoring system is to be provided on the FC gas system, with appropriate instruction and setting criteria by the manufacturer.

The components of the pressure monitoring system in contact with FC exhaust gases are to be corrosion resistant at the expected operating conditions (pressure, temperature…).

7.5 EXHAUST AIR, EXHAUST GAS AND EFFLUENTS VENTING SYSTEM (including excess process air and process waste products)

The FC power system is to be equipped with a ventilation system to convey the products of combustion from FC fuel modules to the outside atmosphere. The provisions of Sec 1, [6.4] and specifically the Regulations for FC machinery spaces, are to be complied with.

In addition to the provisions for ventilation and exhaust contained in the previous items, depending on the selected FC technology, FC spaces will be specially considered for:

- Quantity and arrangement of FC modules / stacks
- Effectiveness of minimum ventilation rate (30 air changes per hour) and flow dynamics to avoid excess heat and gas concentrations in the flammable range in all leakage scenarios within the FC compartment
- Hydrogen properties (range of flammability and ignition) to prevent dilution of flammable gases to a more ignitable concentration range
- Detection and possible shutdown by ESD criteria
- Use of vent panels to prevent worst case consequences of explosions.

The effluent venting system outlets are to be designed and installed taking into account the external air flow, resulting from ship relative wind speed, to prevent any adverse effect (effluent backflow, overpressure…) or unsafe operation leading to a FC power system shutdown.

7.6 CONTROL SYSTEMS AND PROTECTIVE COMPONENTS

A detection system of FC hydrogen leaks is to be provided - in accordance with ISO 26142:2010 *Hydrogen detection apparatus–Stationary applications*, or equivalent international standard - to measure and monitor hydrogen concentrations in FC systems.

One or more independent additional detection systems are to be installed for multilevel safety operations, i.e. including nitrogen purging or ventilation and/or system shut-off, depending on the measured hydrogen concentration.

The hydrogen detection system details are to be submitted, including precision of the system, measuring range, response time, stability, selectivity, etc.

Regardless of the required option (FC SHIP ESSENTIAL or NON-ESSENTIAL) the FC power system are to be designed to prevent cascade failures as a consequence of the single failure of a FC system component.

Automatic electrical and electronic controls of FC power systems are to be designed, constructed and installed to be safe and reliable. The protection parameters of the safety circuits are to be set on the basis of the risk-based analysis specified in Section 2.

Any manual control are to be clearly designed and marked to prevent inadvertent operation and activation.
For additional details see the specific item [9], [10] and [11] of Section 1.

7.7 SAFETY SYSTEMS

The safety systems defined in FC-SHIPS are intended to be additional to the applicable SOLAS regulations.

For details of FC Safety Systems, see [10] and [11] of Section 1.

7.8 AUXILIARY SYSTEMS

7.8.1 PNEUMATIC AND HYDRAULIC POWERED EQUIPMENT

Pneumatic and hydraulic equipment used on of FC power systems are to be designed in accordance with the applicable Tasneef Rules (Part C) and are to be submitted for approval

7.8.2 VALVES

Fuel valves

Fuel lines used to supply the FC power system are to at least pass through a double block and bleed valve.

Shut-off valves

Electrically, hydraulically or pneumatically operated shut-off valves are required on all systems and components where containment or stop of the fuel flow is necessary during shutdown, emergency shutdown, testing or maintenance.

Shut-off valves and the relevant actuators are to be rated for the design service conditions of the fluid (pressure, temperature, chemical characteristics).

Shut-off valves are to be of the fail-safe type in case of loss of actuation energy.

7.8.3 PUMPS, COMPRESSORS AND ROTATING EQUIPMENT

Pumps and compressors and rotating equipment used on FC power systems are to be designed in accordance with the applicable Tasneef Rules (Part C) and are to be submitted for approval.

7.8.4 CABINETS

The FC power system cabinets design and installation are to follow a suitable Technology Qualification Process, to demonstrate that they are fit for purpose throughout their expected life-cycle in the physical environmental conditions expected on board - e.g. temperature range, relative humidity, saline atmosphere, contaminants, dust, ship motions, hull deformations, vibrations, acceleration due to collision or allision, electromagnetic susceptibility, etc. - in accordance with the manufacturer requirements and applicable recognized international standards – see Sec 1, [1.10] for reference.

The cabinets are to be designed to protect the FC power system components and piping contained therein with adequate strength, rigidity, durability, resistance to corrosion, in all operational conditions, including storage and transport.

Cabinet materials, components and accessories (i.e. joints, grids, gaskets…) are to be designed for the physical, chemical and thermal environmental conditions expected throughout life-cycle operations.

The cabinets are to be designed to collect and drain outside for disposal any liquid possibly leaking inside the FC power system.

The cabinets are to have a suitable protection degree of enclosure. Openings in the cabins (e.g. for ventilation) are to be designed to prevent accidental obstructions during normal operation. Clearances and accessibility criteria around the cabinets (e.g. for maintenance) are to be defined by the manufacturer and submitted for approval.

Removable parts are to be easy to fit to ensure appropriate insulation even after repeated removal and/or replacement. Removable parts and components which are not to be manipulated by the user are to be adequately protected by the installer.

Accessibility criteria into the cabinet for inspection, service and maintenance of the FC power system are to be clearly defined by manufacturer guidelines included in the technical documentation to be approved by the Society.

7.8.5 THERMAL INSULATING MATERIALS

Thermal insulating materials used in the cabinet construction are to be compatible with the environmental conditions in operation (physical, chemical, humidity, moisture accumulation etc.) and protected from accidental mechanical damage.

Thermal insulating materials are to be defined in compliance with fire safety requirements (non-combustibility, smoke and toxicity), maintaining the surface temperature within the limits to prevent ignition of adjacent materials.

The manufacturer guidelines are to include and specify health and safety maintenance requirements, accessibility and inspection criteria of the insulating materials, including those in way of piping and fitting penetrations in the cabinet perimeter.

8 FUEL CELLS POWER INSTALLATIONS

The FC power installations include all those systems outside or in addition to the FC power system units, such as process air supply, ancillary systems (not relevant to the process), power conversion systems etc.

In general, FC power installations are to be designed, installed and operated to prevent health or safety hazards and damage to the system in case of interruption of electrical supply, feed water, cooling water, process air.

For the system shut down provisions see [9], [10] and [11] of Section 1.

In case the FC power system requires fresh water to operate, dedicated supply lines are to be provided from a self-contained water source; or fresh water production source, in sufficient quantity during normal operation.

Suitable means - e.g. check valves - are to be provided to prevent backflow of steam or any other contamination into the fresh water supply.

8.1 POWER CONVERSION SYSTEMS (DC / AC)

See Sec 1, [10].

9 FIRE SAFETY

9.1 GENERAL

The provisions in this item are additional to SOLAS Ch. II-2 regulations and the relevant provisions of IGF Code chapter 11 and Tasneef Rules.

The goal of this Part is to provide for fire protection, detection and fighting for all system components related to the storage, conditioning, transfer and use of FC installations.

9.2 PROTECTION AGAINST FIRE

Any space containing equipment for the FC fuel preparation such as pumps, compressors, heat exchangers, vaporizers and pressure vessels is to be regarded as a machinery space of category A for fire protection purposes.

Any boundary of accommodation spaces, service spaces, control stations, escape routes and machinery spaces, facing FC fuel tanks on open deck, are to be shielded by A-60 class divisions.

In addition, fuel tanks are to be segregated from cargo in accordance with the requirements of the International Maritime Dangerous Goods (IMDG) Code where the FC fuel tanks are regarded as bulk packaging. For the purposes of the stowage and segregation requirements of the IMDG Code, a FC fuel tank on the open deck is to be considered a class 2.1 package.

The space containing a FC fuel containment system is to be separated from the machinery spaces of category A or other rooms with high fire risks. The separation is to be done by a cofferdam of at least 900 mm with insulation of A-60 class.

When determining the insulation of the space containing any FC fuel containment system from other spaces with lower fire risks, the fuel containment system is to be considered as a machinery space of category A, in accordance with SOLAS regulation II-2/9. The boundary between spaces containing FC fuel containment systems is to be either a cofferdam of at least 900 mm or A-60 class division. In case of type C tanks, the FC fuel storage hold space may be considered as a cofferdam.

The FC fuel storage hold space is not to be used for machinery or equipment that may have a fire risk.

The fire protection of FC fuel pipes led through ro-ro spaces is to be subject to special consideration by the Society depending on the use and expected pressure in the pipes.

The FC bunkering station is to be separated by A-60 class divisions towards machinery spaces of category A, accommodation, control stations and high fire risk spaces, except for spaces such as tanks, voids, auxiliary machinery spaces of little or no fire risk, sanitary and similar spaces where the insulation standard may be reduced to class A-0.

If an ESD protected FC machinery spaces is separated by a single boundary, the boundary is to be of A-60 class division.

Protection against fire or explosion hazards in FC modules

As a guiding principle, all FC power system and components are to be designed to either prevent explosions in any scenario - or at least minimize any detrimental effect of an explosion without interrupting the FC power system, allowing a safe shutdown of the affected components.

Prevention measures against fire and explosion hazard in fuel preparation rooms, spaces containing the reformer and FC power units inside enclosed cabinets, are to be implemented in accordance with a recognized ISO standard – see Sec 1, [1.10] for reference.

The potential formation of flammables in FC modules is to be managed:

- purging the system before initiating the reaction
- balancing the air-to-fuel ratio in operation
- purging the system as necessary after shutdown
- providing fault monitoring sensors to maintain the reaction process within the design limits
- providing failure monitoring in the FC fuel containment systems
- monitoring potential contamination of air into FC fuel lines, or FC fuel into air pipes
- monitoring pressures and temperatures
- implementing a pre-programmed sequence to contain or manage the propagation of the reaction to other sections of the FC fuel system or to the surrounding space.

9.3 FIRE EXTINCTION

With ref. to SOLAS Ch. II-2 Reg.10 Fire Fighting, the purpose of this item is to suppress and swiftly extinguish a fire in the space of origin. For this purpose, the following functional requirements are to be met:

.1. fixed fire-extinguishing systems are to be installed having due regard to the fire growth potential of the protected spaces; and

.2. fire-extinguishing appliances are to be readily available.

Fire main

When the FC fuel storage tank(s) is located on the open deck, isolating valves are to be fitted in the fire main in order to isolate damaged sections of the fire main.

Isolation of a section of fire main is not to deprive the fire line ahead of the isolated section from the supply of water.

Water spray system

In addition to the provisions of SOLAS Ch. II-2, a water spray system is to be installed for cooling and fire prevention to cover exposed parts of fuel storage tank(s) located on open deck.

The water spray system may be part of the fire main system provided that the required fire pump capacity and working pressure are sufficient for the operation of both the required numbers of hydrants and hoses and the water spray system simultaneously.

The water spray system is also to provide coverage for boundaries of the superstructures, compressor rooms, pump-rooms, cargo control rooms, bunkering control stations, bunkering stations and any other normally occupied deck houses that face the FC storage tank on open decks unless the FC tank is located 10 metres or more from the boundaries.

The system is to be designed to cover all areas as specified above with an application rate of 10 $l/min/m^2$ for the largest horizontal projected surfaces and 4 $l/min/m^2$ for vertical surfaces.

Stop valves are to be fitted in the water spray application main supply line(s), at intervals not exceeding 40 metres, for the purpose of isolating damaged sections. Alternatively, the system may be divided into two or more sections that may be operated independently, provided the necessary controls are located together in a readily accessible position not likely to be inaccessible in case of fire in the areas protected.

The capacity of the water spray pump is to be sufficient to deliver the required amount of water to the hydraulically most demanding area as specified above in the areas protected

If the water spray system is not part of the fire main system, a connection to the ship's fire main through a stop valve is to be provided.

Remote start of pumps supplying the water spray system and remote operation of any normally closed valves to the system are to be located in a readily accessible position which is not likely to be inaccessible in case of fire in the areas protected.

The nozzles are to be of an approved full bore type and they are to be arranged to ensure an effective distribution of water throughout the space being protected.

Dry chemical powder fire-extinguishing system

Portable fire extinguishers are to comply with the requirements of the Fire Safety Systems Code.

Fire extinguishers are to be situated ready for use at easily visible places, which can be reached quickly and easily at any time in the event of a fire, and in such a way that their serviceability is not impaired by the weather, vibration or other external factors.

A permanently installed dry chemical powder fire-extinguishing system is to be installed in the FC bunkering station area to cover all possible leak points. The capacity is to be at least 3,5 kg/s for a minimum of 45 s. The system is to be arranged for easy manual release from a safe location outside the protected area.

In addition to any other portable fire extinguishers that may be required elsewhere in IMO instruments, one portable dry powder extinguisher of at least 5 kg capacity is to be located near the FC bunkering station.

Fire protection of FC spaces

The arrangement of fire extinguishing systems in FC spaces, and the need for water spray for cooling of FC or other components are to be evaluated and approved case by case by the Society for each installation.

9.4 FIRE DETECTION AND ALARM SYSTEM

Detection

In addition to the provisions of SOLAS Ch. II-2 and applicable Tasneef Rules, an approved fixed fire detection and fire alarm system complying with the Fire Safety Systems Code are to be provided for the FC fuel storage hold spaces and the ventilation trunk for fuel containment system below deck, and for all other rooms of the FC fuel gas system where fire cannot be excluded.

The type of fire detection system is to be selected with due consideration of the FC fuels and combustible gases which may be present in each space.

Hydrogen fire detection is to be specifically addressed - hydrogen fire produces no smoke, little heat radiation and an almost invisible flame in daylight.

Smoke detectors alone are not to be considered sufficient for rapid detection of a fire when gaseous FC fuels are used.

The fire detection system is to allow the remote identification of each individual detector; alternatively, the detectors are to be arranged in small separate loops.

10 ELECTRICAL SYSTEMS

10.1 GENERAL – EXPLOSION PREVENTION

The provisions in this item are additional to SOLAS Ch. II-2 regulations and the relevant provisions of IGF Code chapter 12.

Goal

The goal of this item is to provide for the prevention of explosions and for the limitation of effects from explosion in FC installations.

Functional requirements

The probability of explosions is to be reduced to a minimum in FC installations by:

a) reducing number of sources of ignition

b) reducing the probability of formation of ignitable mixtures.

Limitation of explosion consequences

With ref. to IGF Code Ch. 4, 4.2, the preferred safety policy is to be the elimination of either any source of release or any source of ignition, or both. Only in case this is demonstrated not to be feasible, the following applies.

An explosion in any space containing any potential sources of release (double wall fuel pipes are not considered as potential sources of release) and potential ignition sources are not to:

a) cause damage to or disrupt the proper functioning of equipment/systems located in any space other than that in which the incident occurs;
b) damage the ship in such a way that flooding of water below the main deck or any progressive flooding occur;

c) damage work areas or accommodation in such a way that persons who stay in such areas under normal operating conditions are injured;
d) disrupt the proper functioning of control stations and switchboard rooms necessary for power distribution;
e) damage life-saving equipment or associated launching arrangements;
f) disrupt the proper functioning of fire-fighting equipment located outside the explosion-damaged space;
g) affect other areas of the ship in such a way that chain reactions involving, inter alia, cargo, gas and bunker oil may arise; or
h) prevent persons’ access to life-saving appliances or impede escape routes.
i) The aforesaid points are to be demonstrated in a way acceptable to the Society – see also Section 2.

10.2 ELECTRICAL SAFETY

FC electrical systems are to be designed to ensure that FC can be disconnected from the electrical load at any load condition. Protection against excess power is to be provided, either as an integral part of the equipment or as a part of the ships electrical network.

The inverter is to be designed to prevent the transfer of reverse power, e.g. breaking power, into the FC.

The outgoing circuits on a FC system are to be provided with a switch disconnector (ref. IEC60947-3) for isolating purposes, e.g. for maintenance. Contactors are not accepted as isolating devices.

Electric cables in Zone 0 (see Sec 1, [10.3]) are to have armouring or shielding, or are to be laid within a metallic pipe.

Cable penetrations are to be sealed against the passage of gas or vapours.

Equalization connections are to be provided between the bunker supplier and the bunkering station aboard when bunkering.

Power supply connections and penetrations are to be properly designed and installed to prevent the leak of gaseous mixtures.

The FC modules are to be provided with a remote control single emergency switching device, which prevents supply to the load in any mode of operation.

The lighting system in hazardous areas is to be divided between at least two branch circuits. All switches and protective devices are to interrupt all poles or phases and are to be located in a non-hazardous area.

The installation on board of the electrical equipment units is to be such as to ensure the safe bonding to the hull of the units themselves.

For non-hazardous spaces with access from hazardous open deck where the access is protected by an airlock, electrical equipment which is not of the certified safe type is to be de-energized upon loss of overpressure in the space.

Electrical equipment for propulsion, power generation, manoeuvring, anchoring and mooring, as well as emergency fire pumps, that are located in spaces protected by airlocks, is to be of a certified safe type.

Electrical equipment fitted in an ESD-protected machinery space is to fulfil the following:

a) in addition to fire and gas hydrocarbon detectors and fire and gas alarms, lighting and ventilation fans are to be certified safe for hazardous area zone 1; and

b) all electrical equipment in a machinery space containing gas-fuelled engines, and not certified for zone 1 is to be automatically disconnected, if gas concentrations above 40% LEL is detected by two detectors in the space containing gas-fuelled consumers.

The manufacturer of FC power systems is to submit relevant specifications for the electrical safety, based upon recognized international standards, with specific reference but not limited to:
- Protection against electric shock and energy hazards
- Operator access to energized parts
- Electrical components and circuits
- Input current
- Insulation
- Protective earthing
- AC and DC power isolation
- Over-current and earth fault protection.

10.3 AREA CLASSIFICATION AND HAZARDOUS AREA ZONES

Area Classification

Area Classification is a method of analysing and classifying the areas where explosive gas atmospheres may occur. The object of the classification is to allow the selection of electrical apparatus able to be operated safely in these areas.

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 (ref. IEC 60079-10 standard as well as guidance and informative examples given in IEC 60092-502 for tankers).

The principles of the IEC standards are to be applied as guidance also in areas and spaces other than those classified, which are to be subject to special consideration.

Area Classification of a space may be dependent of ventilation as specified in IEC 60092-502, Table 1.

An internal space opening to an adjacent hazardous area on an open deck, may be considered as a less hazardous or non-hazardous space, by means of overpressure.

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

Definition of Hazardous Area Zones

Hazardous area zone 0:

This zone includes, but is not limited to the interiors of fuel tanks, any pipework for pressure- relief or other venting systems for fuel tanks, pipes and equipment containing fuel.

Hazardous area zone 1:

This zone includes, but is not limited to:

a) tank connection spaces, FC fuel storage hold spaces and interbarrier spaces;

b) FC fuel preparation room arranged with ventilation according to Sec 1, [6.4];

c) areas on open deck, or semi-enclosed spaces on deck, within 3 m of any FC fuel tank outlet, gas or vapour outlet, bunker manifold valve, other fuel valve, fuel pipe flange, FC fuel preparation room ventilation outlets and fuel tank openings for pressure release provided to permit the flow of small volumes of gas or vapour mixtures caused by thermal variation;

d) areas on open deck or semi-enclosed spaces on deck, within 1,5 m of fuel preparation room entrances, fuel preparation room ventilation inlets and other openings into zone 1 spaces;

e) areas on the open deck within spillage coamings surrounding gas bunker manifold valves and 3 m beyond these, up to a height of 2.4 m above the deck;

f) enclosed or semi-enclosed spaces in which pipes containing fuel are located, e.g. ducts around fuel pipes, semi-enclosed bunkering stations;

g) the ESD-protected machinery space is considered a non-hazardous area during normal operation, but will require equipment required to operate following detection of gas leakage to be certified as suitable for zone 1;

h) a space protected by an airlock is considered as non-hazardous area during normal operation, but will require equipment required to operate following loss of differential pressure between the protected space and the hazardous area to be certified as suitable for zone 1;

and

j) except for type C tanks, an area within 2.4 m of the outer surface of a fuel containment system where such surface is exposed to the weather.

Hazardous area zone 2:

a) This zone includes, but is not limited to areas within 1.5 m surrounding open or semi-enclosed spaces of zone 1.

b) Space containing bolted hatch to tank connection space.

A space containing FC fuel pipes may be regarded as non-hazardous if the pipes are fully welded and the ventilation rate is sufficient to avoid gas concentration in the flammable range in all leakage scenarios, including pipe rupture.

Electrical equipment or wiring, in general, are not to be installed in hazardous areas unless essential for operational purposes or safety enhancement, and are to be in compliance with a recognized standard.

10.4 INSPECTION AND TESTING OF ELECTRICAL EQUIPMENT IN HAZARDOUS AREA

Where electrical equipment is installed in hazardous areas, it is to be selected, installed and maintained in accordance with recognized standards.

The manufacture, testing, inspection, documentation and maintenance are to be in accordance with recognized standards and the regulations given in the IGF Code.

Equipment for hazardous areas are to be evaluated and certified or listed by an accredited testing authority or notified body recognized by the Society.

The safety, reliability and dependability of the systems are to be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery. A FMEA consistent with the "Tasneef Guide for FMEA" is to be carried out for the whole gas-fuelled system, including process system, electrical power supplies and control system, to check the potential existence of failure modes that can jeopardize the ship's safety. Failure modes and effects of single failure for electrical generation and distribution systems are to be analysed and documented - see also Section 2.

The results of the FMEA are to be used to establish a trial program.

Electrical installations in hazardous areas are to be inspected and tested before coming into service or being considered ready for use.

All electrical equipment installation, including cables, are to be verified in accordance with installation procedures and guidelines issued by the manufacturer, and in accordance with all other applicable rules and regulations.

For spaces protected by (over)pressurisation, or spaces where area classification depends on mechanical ventilation, purge time at minimum flow rate are to be examined, tested and documented for compliance. Required shutdowns and / or alarms are to be also tested.

Safety equipment, protective devices and alarms in hazardous areas are to be verified to test correct settings and/or correct operation.

Intrinsically safe circuits are to be verified to ensure the correct installation of the equipment and wiring.

Verification of the installation is to be documented by the yard and the relevant documentation is to be made available to the Society's site surveyor.

10.5 MAINTENANCE OF ELECTRICAL EQUIPMENT IN HAZARDOUS AREA

The goal of this item is to ensure that operational procedures minimize the risk to personnel, the ship and the environment and that are consistent with practices for a conventional oil fuelled ship.

Maintenance procedures and information for all electrical equipment of FC gas related installations are to be available on board. The ship is to be provided with operational procedures, such that trained personnel can safely operate the FC fuel related systems. The ship is to be provided with suitable emergency procedures.

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.

The manufacturer is to issue a maintenance manual in accordance with IEC 60079-17 and 60092-502 standards, including as a minimum:

- verification of classification of hazardous areas, with information on gas groups and temperature class
- list and location of equipment, technical information, manufacturer's instructions, spares etc. sufficient to enable the certification of safe equipment and life-cycle maintenance
- inspection routines, required level of detail, time intervals between inspections, and acceptance / rejection criteria
- inspection records, including date of inspections and name(s) of person(s) carrying out the inspection / maintenance.

The updated maintenance manual is to be kept on-board, with logbook of date and details of periodical inspections and maintenance.

Inspection and maintenance of installations are to be carried out only by experienced personnel, specifically trained on the various types of protection systems and components installed on the vessel.

11 COMMAND, CONTROL, MONITORING AND SAFETY FUNCTIONS

11.1 GENERAL

The goal of this Part is to provide for the arrangement of command, control, monitoring and safety systems that support an efficient and safe operation of the FC installation – ref. IGF Code Ch. 15.

The life-cycle safety of FC power systems is to be ensured implementing command control and monitoring functions. Such functions are to be performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed on board in planning, directing, coordinating, and controlling resources and operations in the accomplishment of the safety goals.

Such functions, based upon safety procedures and protocols, are to be implemented with the support of the integrated automation system of the ship, or are to be provided with an interface which allows the maximum possible interchange of information and control via the integrated automation system of the ship.

The main features of the system used for command control and monitoring functions are to be preferably:

- process oriented
- using redundant high speed data communication networks
- modular, with fail-safe hardware and on line fault diagnosis, so that no single fault, failure in power supply or system malfunction prevents continued and effective remote plant control and safe ship operation being retained. The design and installation of the various alarm and control systems are to prevent the propagation of faults from one system to another.

Safety systems, which are monitored through the automation system, are to also have remote controls or local manual controls and indications to ensure their availability in the event of partial or total automation system failure.

The following systems (but not limited to), related to FC power installations, can be integrated or interfaced with the ship automation system:

- FC Power management system including mode selection system
- AC / DC converters and switchboards
- Pumps
- Ventilation fans
- Remote control valves and dampers
- Temperature and pressure controllers
- FC tank monitoring and remote level gauging
- Management of all auxiliary and electrical systems related to FC installations

- Water mist and fixed fire suppression systems system
- Fire detection system

The command, control and monitoring systems are to include a reporting system with advanced data logging and report tools such as:
- history log for all signals, events and alarms (digital and analogue)
- storing of all alarms in a database
- facility for daily automatically created reports with log-book feature
- [access to report system from owner's shore head-office via satellite connection]

Components such as instruments, transmitters, pressure switches, temperature switches, controllers, control valves, transmitters, limit switches and proximity switches, etc., are to be able to withstand the ambient conditions in the working environment, e.g. contact with corrosive substances, vibration, rolling and pitching of the ship. They are to be selected to have adequate ranges, sensitivity and response times. Their proper functioning is to be regularly tested, either by built-in auto-test functions or by appropriate verification procedures, following the manufacturer's prescriptions.

All sensors and functions included in the FC automation safety systems are to be marked locally with engraved metal plates near sensor with sign including name or function.

The design and installation of the various alarm and control systems are to prevent the propagation of faults from one system to another.

The following command, control and monitoring systems are to be certified:
- FC fuel tank level gauging
- FC fuel tank overflow protection
- FC fuel supply control and monitoring
- flammable gas detection system
- inert gas control and monitoring system
- oxygen indication equipment (if permanently installed)
- FC power management
- FC safety systems.

Suitable instrumentation devices are to be fitted to allow a local and a remote reading of essential parameters to safeguard the whole FC fuel equipment, including bunkering. Pressure gauges with local reading are required between the stop valve and the connection to shore at each bunker pipe, in the bunkering lines and in the FC fuel pump discharge lines.

A bilge well in each tank room surrounding an independent FC fuel tank is to be provided with both a level indicator and a temperature sensor. Alarm is to be given at high level in the bilge well. Low temperature indication is to activate the safety system.

The provisions of this item and the command, control and monitoring options may be supplemented or amended on the basis of the risk analysis results carried out in accordance with Section 2.

FC power system management
- A safety system is to be arranged to close down the FC gas supply system automatically upon failure in FC systems and upon other fault conditions which may develop too fast for manual intervention
- for ESD protected machinery configurations the safety systems are to shut down the FC gas supply upon gas leakage and,
- in addition, disconnect all non-certified safe type electrical equipment in the machinery space;
- the safety functions are to be arranged in a dedicated FC gas safety system that is independent of the gas control system in order to avoid possible common cause failures. This includes power supplies and input and output signal
- the safety systems including the field instrumentation are to be arranged to avoid spurious shutdown, e.g. as a result of a faulty gas detector or a wire break in a sensor loop; and
- where two or more FC gas supply systems are required to meet the regulations, each system is to be fitted with its own set of independent gas control and gas safety systems.

Start and re-start
- All safeguards are to be in place and functional.
- suitable interlocks are to be provided to secure a correct sequential start.
- the automatic sequential start is to be activated by intentional actuation of a dedicated manual control, after verification that the start is non-hazardous and the safety conditions have been fulfilled.
- restarting of the FC power system is to be possible after a stop, as a normal sequence of an automatic cycle of power management.
- in case of hazardous situations - e.g. start failure of a gas utilization equipment after opening of the FC gas supply valve - the start sequence is to be terminated and the gas supply valve is to be automatically shut-off. Any unburned gas mixture is to be flushed away from the system before starting again the system.

Shutdown

FC power system safety management include Safety Shutdowns, Controlled Shutdowns and Emergency Shutdown sequences.

A **Safety Shutdown** is the automatic de-energization of the main FC fuel flow and/or the de-energization of both process air flow and main FC fuel flow, as the result of any internal fault of the system.

Safety shutdowns are intended to avert present or impending danger beyond normal control of the operation system. The sequence includes:

- stop the system without creating additional hazards or dangerous situations;
- trigger safeguard actions as necessary;
- override all other automatic and manual functions and operations;
- prevent any automatic restart, e.g. by means of hard-switch lock-out, to allow a new start command only after the restart lock-outs have been intentionally reset.

A **Controlled Shutdown** is the automatic de-energization of the main FC fuel flow and/or the de-energization of both process air flow and main FC fuel flow, as the result of triggering a control device (e.g. a thermostat). Conditions which can be safely controlled, or do not cause present or impending danger, may be corrected with a Controlled Shutdown. Depending on the scenario, a Controlled Shutdown may cut all power to the equipment, or may leave power available to the FC power system actuators.

An **Emergency Shutdown** is a manual safety shutdown activated by clearly identifiable, clearly visible and quickly accessible controls (e.g. hard-switches), in accordance with applicable standards (e.g. ISO 13850).

Emergency stops are to stop the fuel and air processing flows, electrically isolate both poles of the FC module, and other electrical sources from the external grid.

In case of fault / failure / damage in the control system logic or hardware:

- the FC power system is to stop when the Emergency Stop command is activated;
- all protection devices and sensors are to remain fully effective and operational;
- the FC power system is not to restart unexpectedly and automatically.

Manual remote Emergency Shutdown of the FC units and the FC fuel supply are to be activated from the following locations:

- navigation bridge or safety centre
- engine control room
- main fire control station

It is to be also possible to activate local manual controls locally (e.g. close to the FC power system). The priority is to be assigned to local activations. A local hard-switch, easy to locate and properly labelled, is to be installed to disconnect the FC power components from any remote control signal which may interfere when in-person inspection and maintenance is in progress. A local disconnection is not to lead to unsafe conditions.

When a protective device or interlock causes a Safety Shutdown or an Emergency Shutdown sequence is activated, the event is to be logged-in to the logic of the control system. The reset of the shutdown function is not to initiate any hazardous condition. Control/monitoring systems are to be designed to operate safely in the hazardous situation and be left energized to continue providing system information.

The FC power system stop controls, including the Emergency Shutdown, are to enable a coordinated shutdown sequence (e.g. with command interfaces), with equipment upstream and/or downstream the FC power system, as necessary.

Any shutdown of the FC power system, that condition is to trigger an alarm in the navigation bridge and in the engine control room.

The operating set points of the FC power system, the FC fuel supply, the corresponding status of the FC equipment and components and the transitions between modes (start /operation / stop), are to be specified and submitted to the Society.

11.2 MONITORING

The FC power system monitoring is to include, but not be limited to:

- dedicated indicators and alarms to maintain all FS installations parameters within the design range, enabling appropriate action to be taken either automatically or manually in case of deviations
- integrated measurements, regulation and control devices, suitable to prevent dangerous overloading (e.g. over-current cut-off switches, temperature limiters, differential pressure switches, flow-meters, time-lag relays, etc.).

Sensors and protective devices are to have adequate ranges and response times, and are to be calibrated and maintained according to the manufacturer’s specifications. The set-points of the system monitoring devices are to be clearly identified at design stage and are to take into account the operating conditions of the installations and possible aberrations in the measuring system to maintain an adequate safety margin beyond the alarm threshold.

All components set with default values by the manufacture, which is not to be manipulated by the user or the installer, are to be appropriately protected. Their design are to preclude accidental manipulation.

11.2.1 LIQUEFIED FC GAS TANK AND BUNKERING

FC gas tanks are to be monitored and protected against overfilling as required in the IGC Code sections 13.2 and 13.3.

Each tank is to be monitored with at least one pressure manometer, with local reading and transmission of the data to the remote control positions. Each manometer is to be clearly marked with the pressure range in the tank (highest and lowest permitted values). Alarms for high-pressure and low pressure (for vacuum protection) are to be triggered on the navigation bridge or in the safety centre before the limit pressures of the safety valves are reached.

The provisions of Tasneef Pt C, Ch. 1, App 7 – 15.4 “Regulations for bunkering and liquefied gas fuel tank monitoring” and 15.5 “Regulations for bunkering control” are to be complied with, as applicable.

11.2.2 GAS COMPRESSOR

FC gas compressors are to be fitted with audible and visual alarms both on the navigation bridge / safety centre and engine control room.

As a minimum the alarms are to include:
- FC gas heater high / low temperature
- FC gas compressor high / low temperature
- FC gas low input pressure
- FC gas low output pressure and high gas output pressure
- Compressor operation
- Lube oil low pressure
- Lube oil high temperature
- Master FC fuel valve status

FC fuel compressors are to shutdown automatically in the event of:
- control air pressure loss
- gas concentration in the compressor room exceeding the limits
- automatic emergency shutdown of FC fuel supply to the FC.

Temperature monitoring for the bulkhead shaft glands and bearings are to be provided, which automatically give a continuous audible and visual alarm on the navigation bridge or in a continuously manned central control station.

11.2.3 FUEL CELL POWER SYSTEM

Irrespective of the selected option, FC SHIP ESSENTIAL or FC SHIP NON-ESSENTIAL, the safety of FC installations is to be equally monitored.

When the option FC SHIP ESSENTIAL is selected, the command, control, monitoring and safety systems of the FC installations are to be so arranged that in the event of single failure the FC system availability and redundancy is maintained, with ref. to the results of the risk-based approach defined in Section 2.

To this end, a FMEA is to be required to identify all possible faults affecting the FC operation. The extent of the additional command, control and monitoring functions are to be consequently decided.

The FC stack, valves, piping, and sensors as well as the corresponding module electronics control and the FC ancillaries may be integrated into a single container, making the best use of the space on board.

The ancillaries of the FC unit comprise the equipment for supplying H2, O2, and N2 for reactant humidification, for product water, and waste heat and residual gas removal. If each FC unit is enclosed in a single container, this is to be filled with N2 inert gas at overpressure to prevent a release of H2 and/or O2 in case of leakages.

In this context, the operator can use the FC as a working “black box” without having to care about each process inside the container. However, as a minimum the following FC power system parameters are to be monitored:
- Voltage and Voltage fluctuations
- temperature
- static and dynamic load current (for currents above the rated current, the overloading time is to be limited due to insufficient heat removal at these values)
- instant air flow and pressure
- fuel flow, temperature, pressure
- exhaust gas temperature
- gas detection in exhaust gas
- water cooling units’ essential parameters (level, pressure, purity)
- parameters necessary to monitor condition-based maintenance and life-cycle deterioration of the FC stacks.

The field data is to be made available (via the integrated automation system) as audible and visual alarms to the navigation bridge / safety centre and engine control room.

The following FC faults may require additional monitoring to prevent potentially hazardous situations:
- FC unit or process fault (e.g. when thermal, pressure, flow or other set parameters are exceeded)
- electrical isolation fault
- low Voltage fault
- overcurrent fault (currents greater than the rated values)

Items which can be subject to these faults are to be designed according to fail-safe principles; recovery procedures and actions are to be pre-programmed to be immediately implemented in case of need.

The most appropriate operating conditions of the FC modules are to be identified by the manufacturer, with clear indication of the working parameter of the connected systems, such as:
- hydrogen and oxygen supply

- disposal units, for functions like:
  - cooling
  - residual gas
  - reaction water
- auxiliary systems, for functions like:
  - inert gas drying
  - de-gasification for cooling fluid
  - nitrogen supply
  - supply of the electrical power to the propulsion/ship's system at the given operational load factor.

Operator control and visualization of the FC system may be facilitated if the monitoring system is integrated with the ship (platform) management system, or directly via a control panel in the FC system.

The FC installation in its entirety – the complete FC power plant, especially the supply and disposal systems – is to be specially considered taking into account the spatial and functional integration on board to ensure adequate accessibility to the FC units and the FC monitoring system.

11.3 GAS DETECTION

In general, the provisions of Tasneef Pt C, Ch. 1, App 7 – 15.8 "Regulations for gas detection" are to apply.

Permanently installed gas detectors are to be fitted in:

- FC tank room,
- all ducts around gas pipes,
- FC spaces,
- compressor rooms,
- other enclosed or semi-enclosed spaces containing FC fuel piping or other FC fuel equipment.

Gas detection equipment is to be designed, installed and tested in accordance with a recognized standard.

In each ESD protected machinery space, redundant gas detection systems are to be provided.

The number of detectors in each space is to be considered taking into account the size, layout and ventilation of the space. CFD simulations, or gas dispersal analysis, or a physical smoke test may be used to find the best possible arrangement of the gas detectors in a space.

Gas detectors are not mandatory in spaces where only completely ducted FC fuel pipes are present.

Gas detection systems are to be suitable for all types of flammable gases that may be released in the space. Continuous detection is required for FC fuel pipe ducts and FC spaces kept gas safe by ventilation and fully welded fuel pipes.

Audible and visible alarms are to be activated, on the navigation bridge / safety centre and in the engine control room, before the vapour concentration reaches 20% of the Lower Explosive Limit (LEL). For ventilated ducts around FC fuel pipes the alarm limit can be set to 30% LEL. The protective system is to be activated at a LEL of 40 %.

For easy reference, LEL is 4% for hydrogen in air, 5.3% for methane in air and 1.7% for propane in air. These thresholds can be adjusted as a consequence of the results of the risk-based approach defined in Section 2.

11.4 SAFETY FUNCTIONS

11.4.1 GAS SUPPLY SYSTEMS

In general, the provisions of Tasneef Pt C, Ch. 1, App 7 – 15.11 "Regulations on safety functions of fuel supply systems" are to apply.

Each FC gas storage tank is to have a remote operated main tank valve, located as close as possible to the tank outlet.

One manually operated shutdown valve in each FC fuel supply line to each FC - upstream of the double block and bleed valves (described here below) – is to provide safe isolation during maintenance on the FC installations.

Each main supply line of FC fuel is to have a remote controlled master fuel valve situated outside the FC space. The master fuel valve is to automatically to cut off the FC fuel supply when required (ref. Table 7) and is to be readily commanded and controlled within the FC space (also in several positions, depending on the layout), from outside the FC space and from the bridge / safety centre.

Each main supply line of FC fuel is also to be equipped with a manually operated stop valve, installed in series or a combined with the master fuel valve ("combined manually and automatically operated valve").

Each FC unit is to have a set of "double block and bleed" valves.

These valves are to be fitted so that when automatic shutdown is initiated - ref. Table 7 - this will cause the two FC fuel valves - which are in series on the FC fuel piping - to close automatically and the vent valve to open automatically, venting to a safe location in open air the portion of the FC fuel that is in the piping between the two valves in series.

The two block valves are to be of fail-to-close type.

The vent valve is to be fail-to-open type.

The double block and bleed valves are also to be used for normal stop of the FC.

An automatic excess flow shut-off valve is to be fitted in each main supply FC fuel line to each FC space where the FC fuel line is not in a double duct.

Such valve is to be designed to shut-off the FC fuel supply in case of rupture of the FC fuel line. However, the shutdown time is to take into consideration transient load variations to prevent unnecessary shutdown. The valve is to be located as near as possible to the penetration of the FC fuel supply line into the FC space. This provision may be reconsidered if the FC fuel lines are located in protected locations, or mechanically shielded.

If the FC fuel supply is shut-off due to activation of a remote controlled valve, the FC fuel supply is not to be opened again until the reason for the valve shut-off is ascertained and the necessary precautions taken.

A readily visible instruction signboard is to be positioned nearby the operating stations of such valves.

Similarly, when a FC fuel leak occurs, resulting in a FC fuel supply shutdown, the FC fuel supply is not to be operated until the leak has been found and solved. Instruction signboards are to be positioned in one or more prominent position(s) within the machinery space.

When the FC is running, heavy lifting, maintenance or other activities capable of potentially causing damage to the FC fuel pipes and components are to be explicitly prohibited.

Instruction signboards are to be positioned in one or more prominent position(s) within the FC space.

Redundant FC power installations in more than one machinery space are to be specially considered.

As an example, when the option FC SHIP ESSENTIAL is selected, the total loss of ventilation in one of these machinery spaces is to result in the automatic shutdown of the FC unit in the same room and the start of the second FC power system.

If there is only one machinery space for the FC power system and ventilation in one of the enclosed ducts around the FC fuel supply lines is lost, the master gas fuel and double block and bleed valves in that supply line are to close automatically, provided the other gas supply line is ready to deliver.

Table 7: Monitoring of FC fuel supply system to FC

Parameter	*Alarm*	*Automatic shutdown of tank valve*	*Automatic shutdown of FC gas supply to FC space*	*Comments*
Gas detection in tank room at 20% LEL	**x**			
Gas detection on two detectors (1) in tank connection space at 40% LEL	**x**	**x**		
Fire detection in FC fuel storage (tank room)	**x**	**x**		
Fire detection in ventilation trunk for fuel containment system below deck	**x**			
Bilge well high level in tank connection space	**x**			
Bilge well low temperature in tank connection space	**x**	**x**		
Gas detection in duct between tank and FC space above 20% LEL	**x**			
Gas detection on two detectors (1) in duct between tank and FC space at 40% LEL	**x**	**x (2)**		
Gas detection in fuel compressor room at 20% LEL	**x**			
Gas detection on two detectors (1) in fuel compressor room at 40% LEL	**x**	**x (2)**		
Gas detection in duct inside FC space at 30% LEL	**x**			If double pipe fitted in FC space
Gas detection on two detectors (1) in duct inside FC space at 60% LEL	**x**		**x (3)**	If double pipe fitted in FC space
Gas detection in ESD protected FC space at 20% LEL	**x**			Gas detection not required if all FC pipes are in complete double ducts

Gas detection on two detectors (1) in ESD protected FC space at 40% LEL	**x**		**x**	Gas detection not required if all FC pipes are in complete double ducts. Is also to disconnection non certified safe electrical equipment in FC space.
Loss of ventilation in duct between tank and FC space	**x**		**x (2)**	
Loss of ventilation in duct inside FC space (5)	**x**		**x (3)**	If double pipe fitted in FC space.
Loss of ventilation in ESD protected FC spaces	**x**		**x**	Not for FC spaces with only completely ducted FC fuel pipes
Fire detection in FC space	**x**		**x**	Also to lead to stop of ventilation in FC space.
Abnormal gas pressure in gas supply pipe	**x**			
Failure of valve control actuating medium	**x**		**x (4)**	Time delayed as found necessary
Automatic shutdown of fuel cell (fuel cell failure)	**x**		**x (4)**	
Manually activated emergency shutdown of fuel cell	**x**		**x**	

(1) Two independent gas detectors located close to each other are required for redundancy reasons. If the gas detector is of self-monitoring type the installation of a single gas detector can be permitted
(2) If the tank is supplying gas to more than one F and the different supply pipes are completely separated and fitted in separate ducts and with the master valves fitted outside of the duct, only the master valve on the supply pipe leading into the duct where gas or loss of ventilation is detected is to close.
(3) If the gas is supplied to more than one FC and the different supply pipes are completely separated and fitted in separate ducts and with the master valves fitted outside of the duct and outside of the machinery space containing gas-fuelled FC, only the master valve on the supply pipe leading into the duct where gas or loss of ventilation is detected is to close
(4) Only double block and bleed valves to close.
(5) If the duct is protected by inert gas then loss of inert gas overpressure is to lead to the same actions as given in this table.

11.4.2 THE FUEL CELL POWER SYSTEM

Whenever the safe operation limits listed in the previous Parts are exceeded, immediate actions are to be taken by means of fail-safe procedures.

These procedures are to be pre-programmed, i.e. examined at design stage and supported by risk-based considerations.

The resulting recommendations are to be specified by the FC manufacturer, targeting risk reduction measures and identifying the actions to be taken for the protection against fire and explosion hazards.

These procedures are to be submitted to the Society, verified against the results of the risk analysis and included in the training scope of the specialized personnel operating the FC power systems on board.

12 MANUFACTURE WORKMANSHIP AND TESTING

12.1 GENERAL

The manufacture, testing, inspection and documentation are to be in accordance with recognized standards and the provisions given in FC-SHIPS.

The general test regulations and specifications applicable to tensile tests, toughness tests, bend tests, are to be in accordance with Tasneef Rules Pt C, Ch 1, App 7, [16.2].

Welding of metallic materials and non-destructive testing for the fuel containment system are to be in accordance with Tasneef Rules Pt C, Ch 1, App 7, [16.3].

Other regulations for construction in metallic materials are to be in accordance with Tasneef Rules Pt C, Ch. 1, App 7, [16.4].

Hydrogen storage and handling procedures are to be based upon recognised international standards, ref. Sec 1, [1.10] (e.g. ISO 16110-1:2007, ISO/TS 15869: 2009, ISO 15399 etc.) for reference.

The complete list and specification of tests to be carried out (factory acceptance tests, commissioning on board and sea trials), as well as the type approval compliance is to be submitted to the Society as part of the design documentation as early as possible - see also Sec 1, [1.6], [1.7] and [1.8].

12.2 (LIQUIFIED) GAS TANKS

Tank materials are to be in compliance with Tasneef Rules Pt C, Ch. 1, App 7 - and specifically item [7.4.1] with ref. to Tables 10 to 14.

Tests related to welding and tank testing are to be in accordance with the IGC Code Ch. 4.10 and 4.11, as applicable.

Testing and inspections during construction are to be in accordance with Tasneef Rules Pt C, Ch. 1, App 7 [16.5] and [16.6].

FC gas storage tank, tank master fuel isolation valve, fuel venting arrangements and - as applicable - the fuel storage hold space, structural fire protection and ventilation arrangements are to be built under the survey of the Society and installed in accordance with approved drawings and certified fit for FC gas fuel operations.

The FC gas tanks are to be certified and approved by the Society.

12.3 FC FUEL PIPING SYSTEMS

Materials for fuel containment and piping systems are to comply with the minimum regulations given in Tasneef Rules Pt C, Ch. 1, App 7 - and specifically [7.4.1] with ref. to Tables 10 to 14.

Type testing of piping components are to be in accordance with Tasneef Rules Pt C, Ch. 1, App 7, [16.7]; for hydrostatic or hydro-pneumatic pressure testing see [16.5.2] to [16.5.5], as applicable.

The use of materials not covered above, may be specially considered by the Society.

All FC piping equipment associated with the gas fuelled system, e.g. pipes, pumps, valves, etc. including all bunkering arrangements and associated access arrangements including structural fire protection as applicable, are to be built and installed in accordance with approved drawings and certified fit for FC gas fuel operations.

12.4 VALVES

Each type and size of valve in piping component intended to be used at a working temperature below minus 55°C is to be subject to the type tests defined in Tasneef Rules Pt C, Ch. 1, App 7, [16.7.1].

Valves for use in hydrogen pipes located in ventilated spaces with fully welded hydrogen pipes, are to be tightness tested with hydrogen to demonstrate that there is no leakage of hydrogen from the valve.

12.5 EXPANSION BELLOWS

Expansion bellows intended for use in FC fuel systems are to be tested in accordance with Tasneef Rules Pt C, Ch. 1, App 7, [16.7.3].

12.6 FUEL CELL POWER SYSTEM

The FC system to be installed on the ship is to be type approved, or a substantial production sample is to be type tested, in accordance with recognised standards (e.g. IEC62282-3-1 and IEC62282-3-2).

At least the following tests are to be carried out, as relevant and applicable:

- FC gas leakage
- coolant (liquid) leakage
- strength of FC gas and liquid sections
- ambient condition measurements
- normal operation
- electric overload
- dielectric, simulating abnormal conditions
- system shutdown
- burner operating characteristics, in case of FC technologies requiring any heating device in the reformer
- automatic control of burners and catalytic oxidation reactors
- exhaust gas temperature
- surface and component temperature
- wind, in case of installation on open deck or enclosed spaces with horizontal air inlets and exhaust to the outdoors
- rain, to verify the corresponding IP rating declared by the manufacturer, according to IEC 60529 or equivalent
- CO emission - except for pure hydrogen use

Routine tests are to be performed on the FC unit on board, to verify at least:

- FC gas leakage
- coolant (liquid) leakage
- normal operation
- dielectric, simulating abnormal conditions
- burner operating characteristics
- CO emission, except for pure hydrogen use

12.7 MARKING AND LABELLING

Marking plates details are part of the documentation to be submitted for approval, ref. Tasneef Rules Pt C, Ch. 1, App 7, [1.2] and Table 2.

Any marking of the pressure vessels is to be achieved by a method that does not cause unacceptable local stress increase.

FC gas pipes are to be colour marked in accordance with a recognised standard, e.g. EN ISO 14726.

Piping systems and high voltage equipment are to be marked according to applicable Rules.

The FC power system labelling is to include a data plate clearly stating essential information, e.g. any restrictions in use, need of sufficient ventilation, hazardous area classification rating (ref. IEC 60079-10-1), electrical input/output ranges, FC fuel type, supply pressure, range of ambient temperature, and any other information suitable for a safe installation and operation of the system - see also IEC 62282-3-1 for guidance.

All user serviceable parts of the FC installation are to be identified to match the installation drawings and the user's manual.

Caution signs are to be appropriately fitted to identify hazards (e.g. electrical, hot components) related to the FC installation.

Control devices, visual indicators and displays used in the human-machine interface (HMI) are to be clearly marked with their functions.

Standard symbols are to be used.

13 OPERATIONAL REQUIREMENTS, MAINTENANCE AND LIFE-CYCLE COMPLIANCE

The goal of this item is to ensure that operational procedures for the loading, storage, operation, maintenance, and inspection of systems for FC installations minimize the risk to personnel, the ship and the environment and that are consistent with practices for a conventional oil fuelled ship whilst taking into account the nature of the liquid or FC gas fuel used by the FC installations.

Ref. is made to Tasneef Rules Pt C, Ch. 1, App 7, [18] for the following aspects:
- Functional requirements ([18.2])
- Regulations for maintenance ([18.3])
- Regulations for bunkering operations ([18.4])
- Regulations for enclosed space entry ([18.5])
- Regulations for inerting and purging of FC fuel systems ([18.6])

The operating manual is to address all necessary verifications for set-up, start up and use the FC installation.

The operating manual is also to include a dedicated safety section with the list of potential hazards and safety-related instructions for the specific FC installation.

Where the operations of FC installations are programmed using a dedicated software, detailed information on logic and methods of programming, software verification and integrity are to be provided.

Maintenance procedures and information for all FC installations are to be available on board.

The power deterioration rate for the FC components is to be specifically considered and documented through analysis and/or test results, with reference to the expected different life-cycle power levels and maintenance requirements, to maintain the expected operational performance of the FC systems.

A dedicated maintenance manual is to be prepared for the FC gas supply system, the FC power system and for the command control and monitoring of safety systems.

The maintenance manual is to detail proper procedures for adjustment, servicing, preventive inspection, and repair. It is to safeguard the recommendations of the equipment manufacturer on maintenance.

Servicing instructions and records are to be part of the maintenance manual.

The maintenance manual is to include complete instructions on:
- personnel qualification to carry out maintenance.
- starting and shutting down the FC installation for maintenance - on board displayed instructions are to pictorially illustrate and locate all relevant components.
- Intervals for maintenance or replacement of gas valves
- frequency and mode for replacing FC individual cells, spare parts and filters
- regular and routine examination and maintenance activities on the FC installation components by qualified service personnel
- maintenance procedures for all components of the command control and monitoring systems, in accordance with the recommendations of the equipment supplier
- recommended methods for periodic cleaning of necessary parts
- lubrication of moving parts, including type, grade and amount of lubricant.
- examining criteria for the FC power system installation to prevent obstructions, or physical deterioration
- periodic examination of the venting system, FC gas detectors and related functional parts.
- ordering spare or replacement parts.
- procedures for neutralizing condensate or water infiltration, as appropriate.

Maintenance and repair procedures are to include considerations with respect to the FC tank location and adjacent spaces

In-service survey, maintenance and testing of the FC fuel containment system are to be carried out in accordance with the inspection/survey plan.

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.

In principle, adjustment, maintenance, repair, cleaning and servicing operations are to be carried out while the FC power system is at a standstill. If carried out while the FC power system is operating, provisions are to be taken so that such functions can be performed without the risk of injury.

FC installation components to be changed frequently are to be removed and replaced without the risk of injury. The necessary instructions and tools are to be provided in accordance with the manufacturer recommendations

Safety instructions or pictorial diagrams are to be displayed near FC installation, using a permanent method and materials, resistant to the environmental conditions of use.

13.1 ON-BOARD TESTING OF FC INSTALLATIONS

On-board testing of fc installations is to be performed in different load conditions - typically “start-up”, “normal running”, “full load”.

The tests will be aimed at verifying that the FC system is automatically transferred into a safe condition in the event of the following faults:

- fire detection alarm
- FC gas detection system alarm
- power supply failure
- programmable logic controllers (PLCs) failure
- triggering of the protective devices
- protective devices faults
- protective system faults

Additional tests may be required based on the results of the risk-based analysis, FMEAs and related test programs.

When the option FC-SHIPS-ESSENTIAL is selected, a set of additional tests is to be required to assess the redundancy and availability of the FC power supply, as a result of the risk-based analysis and FMEAs, including, but not limited to:

- power generation by the FC system alone
- FC system together with conventional shipboard generation of electrical power
- FC system together with batteries
- change-over to the emergency source of electrical power
- switching the FC system online or offline
- testing of sudden load variations and load rejection

If the FC system constitutes the main propulsion system of the ship, it is to be verified that the ship has adequate propulsion power in all manoeuvring situations.

14 TRAINING

Ref. Tasneef Rules Pt C, Ch. 1, App 7, [19].

The goal of this item is to ensure that seafarers on board ships to which FC-SHIPS applies are adequately qualified, trained and experienced.

Companies are to ensure that seafarers on board ships using FC gases are to have completed training to attain the abilities that are appropriate to the capacity to be filled and duties and responsibilities to be assumed, taking into account the provisions given in the STCW Convention and Code, as amended.

In particular, the company is to document that the personnel have acquired the necessary knowledge, appropriate to their duties, as necessary under emergency conditions, and that this knowledge is maintained at all times.

In particular, officers are to be trained in emergency procedures to deal with conditions of leakage, spillage or fire involving the FC installations and a sufficient number of them are to be instructed and trained in essential first aid.

Specific training is to be provided by the FC system manufacturer, by the gas provider and by any other stakeholder having an in-depth knowledge of the safe operation and maintenance of the specific FC system installed on board.

FC gas emergency exercises are to be conducted at regular intervals.

Safety and response systems for the handling of the emergency situations are to be based upon the results of the risk-based approach.

A training manual is to be developed, with a training schedule and drills specifically defined for each individual vessel and its specific FC gas installations.

Section 2

1 RISK-BASED APPROACH FOR HYDROGEN AND FUEL CELLS IN SHIPS

1.1 PURPOSE

The provisions of Section 1 of FC-SHIPS are to be supplemented by the application of risk management methodologies towards a risk-based approach of hydrogen and FC installations in ships, in all instances where the applicable Rules and Regulations - under the provisions of SOLAS or subsidiary IMO Codes - do not address adequately the novel design features.

1.2 REFERENCES

In recognizing that development of prescriptive regulations cannot always keep pace with technical innovation, the IMO introduced regulations to allow for the development of Alternative Designs and Arrangements to demonstrate that new or novel designs, challenging prescriptive rules, provide a level of safety at least equivalent to that provided by prescriptive regulations.

The risk-based approach outlined in this Section 2 is based upon guidance contained in the following IMO documents:

- MSC.1/Circ.1455 “Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments”
- MSC-MEPC.2/Circ.12/Rev.1 “Formal Safety Assessment”, as far as applicable to guidance on the application of risk management techniques in risk-based design studies.
- Annex 3 of MSC-MEPC.2/Circ.12/Rev.1 Guidance on Qualitative and Quantitative risk management techniques that can be applied in risk based design studies.
- Annex 5 of MSC-MEPC.2/Circ.12/Rev.1 Guidance on the development of Risk Evaluation Criteria for risk assessment.

The influence of the human element is to be duly considered in the risk evaluation, based upon guidance contained in these IMO documents and guidelines.

1.3 APPLICATION

Goal

The goal of Section 2 of FC-SHIPS is to provide for safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery equipped with FC installations using gas or low-flashpoint fuel as fuel.

The necessary assessments of the risks involved are to be carried out to eliminate or mitigate any adverse effect to the persons on board, the environment or the ship.

Functional requirements

The safety, reliability and dependability of FC installations is to be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery.

A FMEA consistent with the "Tasneef Guide for FMEA" is to be carried out for the whole gas-fuelled system, including process system, electrical power supplies and control system, to check the potential existence of failure modes that can jeopardize the ship's safety.

The results of the FMEA are then to be used to establish a trial program.

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

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

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

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

Unintended accumulation of explosive, flammable or toxic FC gas concentrations are to be prevented.

System components are to be protected against external damages.

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

Fuel supply, storage and bunkering arrangements are to be safely and suitably arranged, and are to be capable of receiving and containing the FC fuel in the required state without leakage.

Piping systems, containment and over-pressure relief arrangements are to be of suitable design, construction and installation for their intended application.

FC power systems are to be designed, constructed, installed, operated, maintained and protected to ensure safe and reliable operation.

FC fuel containment system and FC power units containing source that might release gas into the space are to be arranged and located such that a fire or explosion in either will not lead to an unacceptable loss of power or render equipment in other compartments inoperable.

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

Fixed gas detection systems are to be arranged, and are to be suitable for all spaces and areas concerned.

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

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

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.

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

Risk-based approach

A risk-based approach broadly consists of three stages:

- Risk Analysis - identifying hazards and analysing the consequences and frequency of the hazards.
- Risk Assessment - evaluating risk in qualitative or quantitative terms
- Risk Management - evaluating the information from Risk Assessment and Risk Analysis, deciding if the risk can be accepted, with or without further risk mitigation measures

A Design Team is to be established, responsible for developing the design and the risk-based approach for the FC installations. Design Team members will normally represent the following stakeholders:

- designers: builder/designer, equipment manufacturer
- users: owner, ship's staff, ship operators
- specialists / experts, marine surveyors, safety engineers, human factors experts, as necessary
- maintainers: owner, ship's staff, ship operators, contractors (if delegated maintenance roles).

Design Team members are to be adequately trained and experienced in the application of risk management techniques and are to have the necessary knowledge and experience in safety, design and/or operation as necessary for the specific evaluation at hand

Risk analysis is more commonly referred to as Hazard Identification, aimed at identifying:

- The hazard in a given scenario
- The resulting consequences
- Existing risk mitigation measures in place
- Recommendations for additional controls and risk mitigation measures.

The risk analysis required for the FC installation systems are to specifically focus on the scenario of a FC:

- system failure
- gas leakage which may lead to fire and/or explosion

See also additional guidance in Sec 2, [1.4].

The risk analysis is to primarily identify the spaces in which explosive mixtures may be present, evaluating the likelihood of their ignition and explosion and the associated consequences.

Likelihood criteria is to be expressed in terms of Frequency or Probability.

Hazards will be ranked in terms of Intolerable / ALARP / Broadly Acceptable risk. Hazards having a risk ranking of Intolerable / ALARP are to require further consideration.

Risk assessment is normally conducted using Qualitative (risk ranking) or Quantitative (e.g. Event Tree Analysis) risk assessment techniques. However, due to the lack of reliable accident / near miss / failure data of FC installation in the marine industry, it is not expected that Quantitative analysis will always be possible.

For the purpose of risk assessment to determine equivalence to SOLAS, consequence criteria is to be expressed in terms of Life Safety.

Consequence criteria for Life Safety is to be expressed in terms of ill health, injury, individual fatality and, if appropriate, multiple fatalities.

Individual fatality and multiple fatalities are to be considered in terms of Individual Risk and Societal Risk.

The acceptable upper and lower boundaries of the ALARP region for an individual fatality are to be referred to Table 1 of Appendix 5 to MSC-MEPC.2/Circ.12/Rev.1.

Societal Risk may be defined using F-N diagrams.

In considering whether a risk is in the ALARP zone, a Cost Benefit Analysis may be required. Appendix 7 of the Annex to MSC-MEPC.2/Circ.12/Rev.1 gives guidance in use of Cost Effectiveness, based upon

NCAF or GCAF criteria, to be applied for consequences involving individual or multiple fatalities.

Alternative methods of evaluating CBA's are to be justified and submitted for agreement.

On completion of the risk management process, the Design Team may have identified a number of recommendations to address and mitigate the identified risks.

Such recommendations are to be:
- assigned to an individual for implementation
- time limited for completion
- included in the final report
- confirmed by practical tests on board.

1.4 GENERAL GUIDANCE FOR THE RISK ANALYSIS

Single failure concept

When the option FC-SHIPS-ESSENTIAL on the use of FC power generation and supply systems is selected by the Owner, the analysis are to be based upon the single failure concept, i.e. only one failure mode needs to be considered at the same time.

Both detectable and non-detectable failures are to be considered.

Consequences failures of other component(s) caused by a single failure are also to be considered.

Scope of the risk analysis

The scope of the risk analysis is to:
- identify all the possible failures in the FC installations which could possibly lead to a loss of the assigned functions.
- identify the failure detection method.
- evaluate the consequences.
- identify the corrective measures in design (e.g. system design, redundancy, safety monitoring or alarms, etc.) and in operation (e.g. activation of redundancy, or alternative modes of operation).

FC systems to be analysed

The following systems and functions, as a minimum, are to be analysed:
- FC fuel gas piping system, including pumps, heat exchangers, valves, pipes and fittings, control and monitoring equipment, refuelling system, etc.
  - Scope: maintain FC gas pressure, temperature and flow rate at the FC units in all ship operational conditions.
- Fuel gas containment / ventilation systems, including FC gas piping system enclosures (double wall pipes or ducts, casings, etc.), ESD machinery spaces and the associated ventilation systems.
  - Scope: contain within the enclosures any gas leakage, maintain a de-pressurized enclosure with respect to the adjacent spaces, ensure an efficient exhaust of the leaking gas from the enclosure and an efficient detection of any gas leakage.
- Gas detection systems, including FC gas centralized monitoring unit and its power supply and wiring.
  - Scope: maintain the FC gas leak detection capability and gas concentration in the air
- Command, control, monitoring and safety functions, of FC gas system supply and ventilation system
  - Scope: maintain the target functions
- FC power system, including the subsystems (reforming, FC modules, oxidant processing system, thermal / cooling systems, water treatment system, power control systems, etc.).
  - Scope: converting the FC fuel as stored on board into available electrical power.
- Other ship systems, which could directly or indirectly influence the FC fault or unavailability
  - Scope: maintain the safety and availability of the FC power installations

FC power system units' risk analysis

In addition to the FC systems listed above, specific and detailed consideration is to be given to the risk analysis of the FC power system units, recognizing that prescriptive regulations are not yet ready or sufficiently supported by operational experience on ship installations.

Scope of the risk analysis is to identify the hazards inherent to novel designs, to be consequently managed to provide a level of safety at least equivalent to that resulting in the application of prescriptive regulations.

When the option FC-SHIPS / ESSENTIAL on the use of FC power generation and supply systems is selected, a safety and reliability analysis of the FC power system are to be performed. The analysis is to include the hazards associated to the connection of the FC to the grid potentially affecting the ship's total electrical power generating system, to prevent or minimize black-out risk.

In case of gas leakage anywhere in the FC spaces, the actions from the automatic command, control and monitoring safety system are not to result in the loss of ship essential functions, including propulsion and electrical power availability.

The Design Team is to carry-out the risk analysis of the FC power systems - irrespective of the ESSENTIAL or NON-ESSENTIAL options - to identify all foreseeable hazards, hazardous situations and events associated with the FC power systems throughout their anticipated life-cycle.

The risk of each of such hazards is to be estimated as a combination of probability of occurrence and foreseeable severity.

The risk analysis is, at least, to cover the following:

- FC gas-related components and of FC unit components
- FC gas leakage
- FC control system
- FC fuel processing system
- FC thermal management system
- FC oxidant processing system
- FC water treatment and water discharge systems
- Deviations from the design parameters of air- and gas- FC fuel quality
- Deviation from any FC unit process parameter (HAZOP analysis)
- Any other foreseeable abnormal operating condition of the FC units

In principle, ignition of a gas explosive mixture resulting in an explosion in a FC space is not:

- cause damage to any other adjacent space
- disrupt the proper functioning of any other adjacent zone
- cause ship flooding or progressive flooding
- damage any adjacent work- or accommodation area or cause harm to the occupants
- impair the essential power distribution (e.g. availability of control stations and switchboard rooms)
- result in unavailability of life-saving appliances
- result in unavailability of fire-fighting systems outside the damaged space
- generate chain reactions (fire, explosion) in other ship spaces.

1.5 RISK ASSESSMENT

A risk assessment is to be conducted to ensure that risks arising from the use of FC fuels affecting persons on board, the environment, the structural strength or the integrity of the ship are addressed.

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 analysed using acceptable and recognized risk analysis techniques, and loss of function, component damage, fire, explosion and electric shock as a minimum are to be considered.

The analysis are to ensure that risks are eliminated wherever possible.

Risks which cannot be eliminated are to be mitigated as necessary.

Details of risks, and the means by which they are mitigated, are to be documented to the satisfaction of the Society.

Guidance on risk analysis techniques can be found in the "Tasneef Guide for Risk Analysis".

The assumptions for the risk assessment are to be agreed by the Design Team to the satisfaction of the Administration.

2 CASE-BY-CASE APPROVAL PROCESS

The FC risk-based design is to be ship specific.

Individual assessments are to be produced for each vessel.

However, the results can be applied to a series of sister ships, subject to the following conditions:

- the sister ships are identical in design, arrangement, outfitting and construction
- the ships are built by the same Builder for the same ship Owner.

2.1 ALTERATIONS OR MODIFICATIONS AFFECTING THE VALIDITY OF THE RISK ANALYSIS

The ship Owner is to notify the Society of any proposed alterations to the vessel affecting FC installations.

The Society is to review the proposal and determine the extent to which the proposed alteration affects the assumptions, the original basis for approval, or the operational restrictions stipulated for the FC installations.

Where appropriate, it may be necessary to undertake a new risk analysis.

3 RISK-BASED APPROACH AND APPROVAL PROCESS

The complete risk-based approach is to be based upon the IMO documents and guidelines listed above, and is generally to consist of the following steps, which are to be properly documented and approved by the Society:

- Preparation and design team
- Problem definition and terms of reference
- Historic data collection (if available)
- Risk analysis ad hazard identification
- Risk assessment
- Qualitative analysis
- Quantitative analysis (if applicable)
- Risk evaluation criteria (ALARP principle)
- Risk control measures
- Cost / benefit analysis (where applicable)
- Recommendations and final reporting – including documentation and references.

All steps of the risk-based approach are to be consistently reflected in a final report, to be submitted to the Society.

The necessary risk mitigation actions are to be implemented in relation to risks that have not been ranked as broadly acceptable.

A test program is to be defined for the verification of the main conclusions from the FMEA and any risk mitigation system identified by the assessment.

The risk mitigation actions are also to be aimed at ensuring the continued validity of the results for the effective life-cycle implementation of the risk mitigation actions, during construction and in service as part of the Safety Construction, Safety Equipment or Passenger Ship Safety Surveys and at Safety Management Certificate Audits.

The Society is to review all submitted documentation prior to submission to the Flag Administration. The Society is to advise the Design Team of the findings from their review and, if necessary, require the Design Team to update the documentation accordingly before submission to the Flag Administration.

Final approval of FC installations documents and of the risk assessment is only to be given by the ship's Flag Administration.

4 OPERATIONAL CONSIDERATIONS

4.1.1

It is the responsibility of the ship Owner to ensure that the basis for approval of the FC installations are maintained throughout the life-cycle of the vessel and that any operational conditions or restrictions on which approval is granted are implemented.

Operational measures or restrictions required by the risk analysis results are to be taken into account by the ship Owner within the company's Safety Management System (SMS).

- simulation of communication failure,
- insulation resistance test,
- correct operation of ventilation, cooling, gas detection system, fire detection system and fire extinguishing system, etc., where provided.

4.1.2

Battery system is to be surveyed periodically for the purpose of ascertaining the satisfactory condition of all components and the correct operation of the system.

At the discretion of Tasneef, the checks may be carried out directly by the Manufacturer of the installation or y the person responsible for maintenance authorized by the above-mentioned Manufacturer and certified by the appointed Tasneef Surveyor.