

INTERNATIONAL STANDARD



**Fuel cell technologies –
Part 3-100: Stationary fuel cell power systems – Safety**



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Part 3-100: Stationary fuel cell power systems – Safety**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FUEL CELL TECHNOLOGIES –

Part 3-100: Stationary fuel cell power systems – Safety

FOREWORD

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International Standard IEC 62282-3-100 has been prepared by IEC technical committee 105: Fuel cell technologies.

This second edition cancels and replaces the first edition published in 2012. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) recognition that fuel carrying components qualified to leakage standards (soundness) need not be considered as potential flammable leak sources;
- b) new Annex C for small power systems; and
- c) clarifications for numerous requirements and tests.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
105/695/FDIS	105/705/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62282 series, published under the general title *Fuel cell technologies*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

A typical stationary fuel cell power system is shown in Figure 1.

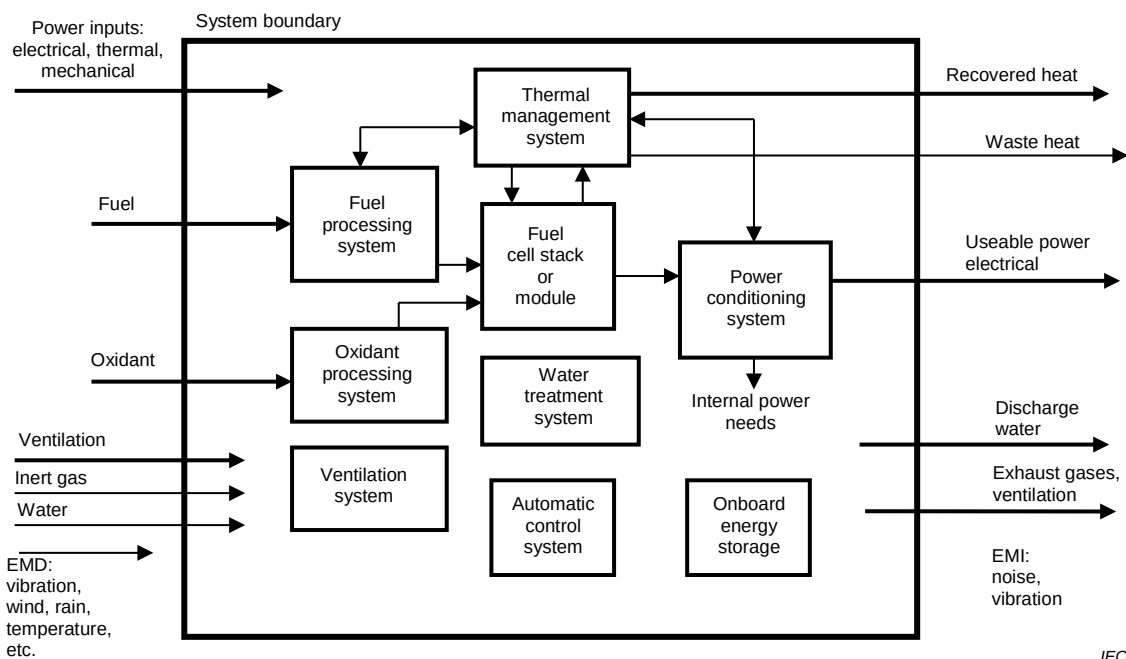


Figure 1 – Typical stationary fuel cell power systems

The overall design of the power system anticipated by this document forms an assembly of integrated systems, as necessary, intended to perform designated functions, as follows.

- Fuel processing system – System of chemical and/or physical processing equipment plus associated heat exchangers and controls required to prepare, and if necessary, pressurize, the fuel for utilization within a fuel cell power system.
- Oxidant processing system – System that meters, conditions, processes and may pressurize the incoming supply for use within the fuel cell power system.
- Thermal management system – System that provides heating or cooling and heat rejection to maintain the fuel cell power system in the operating temperature range, and may provide for the recovery of excess heat and assist in heating the power train during start-up.
- Water treatment system – System that provides all the necessary purification treatment of the recovered or added water for use within the fuel cell power system.
- Power conditioning system – Equipment that is used to adapt the electrical energy produced by the fuel cell stack(s) to application requirements as specified by the manufacturer.
- Automatic control system – System(s) that is composed of sensors, actuators, valves, switches and logic components that maintain the fuel cell power system parameters within the manufacturer's specified limits including moving to safe states without manual intervention.
- Ventilation system – System that provides air through ~~forced~~ mechanical or natural means to the fuel cell power system's enclosure.
- Fuel cell modules – Equipment assembly of one or more fuel cell stacks which electrochemically converts chemical energy to electric energy and thermal energy intended to be integrated into a power generation system.

- Fuel cell stack – Equipment assembly of cells, separators, cooling plates, manifolds and a support structure that electrochemically converts, typically, hydrogen rich gas and air reactants to DC power, heat and other reactant bi-products.
- Onboard energy storage – System of internal electric energy storage devices intended to aid or complement the fuel cell module in providing power to internal or external loads.

FUEL CELL TECHNOLOGIES –

Part 3-100: Stationary fuel cell power systems – Safety

1 Scope

This part of IEC 62282 applies to stationary packaged, self-contained fuel cell power systems or fuel cell power systems comprised of factory matched packages of integrated systems which generate electricity through electrochemical reactions.

This document applies to systems

- a) intended for electrical connection to mains direct, or with a transfer switch, or to a stand-alone power distribution system;
- b) intended to provide AC or DC power;
- c) with or without the ability to recover useful heat;
- d) intended for operation on the following input fuels:
 - 1) natural gas and other methane rich gases derived from renewable (biomass) or fossil fuel sources, for example, landfill gas, digester gas, coal mine gas;
 - 2) fuels derived from oil refining, for example, diesel, gasoline, kerosene, liquefied petroleum gases such as propane and butane;
 - 3) alcohols, esters, ethers, aldehydes, ketones, Fischer-Tropsch liquids and other suitable hydrogen-rich organic compounds derived from renewable (biomass) or fossil fuel sources, for example, methanol, ethanol, di-methyl ether, biodiesel;
 - 4) hydrogen, gaseous mixtures containing hydrogen gas, for example, synthesis gas, town gas.

This document does not cover:

- micro fuel cell power systems;
- portable fuel cell power systems;
- propulsion fuel cell power systems.

NOTE For special applications such as “marine auxiliary power”, additional requirements ~~may~~ can be given by the relevant marine ship register standard.

This document is applicable to stationary fuel cell power systems intended for indoor and outdoor commercial, industrial and residential use in non-hazardous ~~(unclassified)~~ areas.

This document contemplates all significant hazards, hazardous situations and events, with the exception of those associated with environmental compatibility (installation conditions), relevant to fuel cell power systems, when they are used as intended and under the conditions foreseen by the manufacturer.

This document deals with conditions that can yield hazards on the one hand to persons, and on the other to damage outside the fuel cell **power** system only. Protection against damage to the fuel cell **power** system internals is not addressed in this document, provided it does not lead to hazards outside the fuel cell **power** system.

~~The requirements of this standard are not intended to constrain innovation. When considering fuels, materials, designs or constructions not specifically dealt with in this standard, these alternatives shall be evaluated as to their ability to yield levels of safety and performance equivalent to those prescribed by this standard.~~

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60079-0, Explosive atmospheres – Part 0: Equipment – General requirements~~

IEC 60079-2, Explosive atmospheres – Part 2: Equipment protection by pressurized enclosure "p"

~~IEC 60079-10 (all parts), Explosive atmospheres – Part 10: Classification of areas~~

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

IEC 60079-29-1, Explosive atmospheres – Part 29-1: Gas detectors – Performance requirements of detectors for flammable gases

IEC/IEEE 60079-30-1, Explosive atmospheres – Part 30-1: Electrical resistance trace heating – General and testing requirements

IEC 60204-1, Safety of machinery – Electrical equipment of machines – Part 1: General requirements

IEC 60335-1:2010 2016, Household and similar electrical appliances – Safety – Part 1: General requirements

IEC 60335-2-51, Household and similar electrical appliances – Safety – Part 2-51: Particular requirements for stationary circulation pumps for heating and service water installations

~~IEC 60417, Graphical symbols for use on equipment. Available from: <<http://www.graphical-symbols.info/equipment>>~~

IEC 60529:1989, Degrees of protection provided by enclosures (IP Code)

IEC 60730-1, Automatic electrical controls ~~for household and similar use~~ – Part 1: General requirements

IEC 60730-2-5, Automatic electrical controls ~~for household and similar use~~ – Part 2-5: Particular requirements for automatic electrical burner control systems

IEC 60730-2-6, Automatic electrical controls ~~for household and similar use~~ – Part 2-6: Particular requirements for automatic electrical pressure sensing controls including mechanical requirements

IEC 60730-2-9, Automatic electrical controls ~~for household and similar use~~ – Part 2-9: Particular requirements for temperature sensing controls

IEC 60950-1, Information technology equipment – Safety – Part 1: General requirements

IEC 61000-3-2, Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic currents & emissions (equipment input current ≤16 A per phase)

IEC 61000-3-3, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*

IEC **TS** 61000-3-4, *Electromagnetic compatibility (EMC) – Part 3-4: Limits – Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A*

IEC **TS** 61000-3-5, *Electromagnetic compatibility (EMC) – Part 3-5: Limits – Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 75 A*

IEC 61000-3-11, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subject to conditional connection*

IEC 61000-6-1, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity **standard** for residential, commercial and light-industrial environments*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity **standard** for industrial environments*

IEC 61000-6-3, *Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments*

IEC 61000-6-4, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61511-1, *Functional safety – Safety instrumented systems for the process industry sector – Part 1: Framework, definitions, system, hardware and application programming requirements*

IEC 62040-1, *Uninterruptible power systems (UPS) – Part 1: ~~General and~~ Safety requirements for UPS*

IEC 62061, *Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems*

~~IEC/TS 62282-1, Fuel cell technologies – Part 1: Terminology~~

~~IEC 62282-3-200, Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test methods~~

IEC 62368-1, *Audio/video, information and communication technology equipment – Part 1: Safety requirements*

ISO 3864-2, *Graphical symbols – Safety colours and safety signs – Part 2: Design principles for product safety labels*

ISO 4413, *Hydraulic fluid power – General rules and safety requirements for systems and their components*

ISO 4414, *Pneumatic fluid power – General rules and safety requirements for systems and their components*

ISO 5388, *Stationary air compressors – Safety rules and code of practice*

~~ISO 7000, Graphic symbols for use on equipment – Index and synopsis. Available from: <http://www.graphical-symbols.info/equipment>.~~

ISO 10439 (all parts), *Petroleum, petrochemical and natural gas ~~service~~ industries – Axial and centrifugal compressors and expander-compressors*

ISO 10440-1, *Petroleum, petrochemical and natural gas industries – Rotary-type positive-displacement compressors – Part 1: Process compressors*

ISO 10440-2, *Petroleum and natural gas industries – Rotary-type positive-displacement compressors – Part 2: Packaged air compressors (oil-free)*

ISO 10442, *Petroleum, chemical and gas service industries – Packaged, integrally geared centrifugal air compressors*

ISO 12499, *Industrial fans – Mechanical safety of fans – Guarding*

ISO 13631, *Petroleum and natural gas industries – Packaged reciprocating gas compressors*

ISO 13707, *Petroleum and natural gas industries – Reciprocating compressors*

ISO 13709, *Centrifugal pumps for petroleum, petrochemical and natural gas industries*

ISO 13849-1, *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design*

ISO 13850, *Safety of machinery – Emergency stop ~~function~~ – Principles for design*

ISO 14847, *Rotary positive displacement pumps – Technical requirements*

ISO 15649, *Petroleum and natural gas industries – Piping*

ISO 16111, *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*

ISO 23550, *Safety and control devices for gas and/or oil burners and ~~gas-burning~~ appliances – General requirements*

ISO 23551-1, *Safety and control devices for gas burners and gas-burning appliances – Particular requirements – Part 1: Automatic and semi-automatic valves*

ISO 23553-1, *Safety and control devices for oil burners and oil-burning appliances – Particular requirements – Part 1: ~~Shut-off devices for oil burners~~ Automatic and semi-automatic valves*

ISO 26142, *Hydrogen detection apparatus – Stationary applications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

accessible

area to which, under normal operating conditions, one of the following applies:

- a) access can be gained without the use of a tool;
- b) the means of access is deliberately provided to the ~~end~~-user;
- c) the ~~end~~ user is instructed to enter regardless of whether or not a tool is needed to gain access

Note 1 to entry: The terms "access" and "accessible", unless qualified, relate to ~~end-user access area~~ an area deemed accessible as defined above.

Note 2 to entry: Only service ~~technicians~~ personnel are allowed into non-accessible areas. Service personnel ~~that are allowed access into non-accessible areas~~ may need to have proper personal protective equipment as noted in the maintenance manual.

3.2

anode exhaust catalytic reactor

catalyst reactor which oxidizes hydrogen-rich gas used for hydrogen fuel cell power systems

3.3

automatic burner control system

system which ~~monitors the operation of fuel burners. It~~ includes a programming unit, a flame/~~oxidation~~ detector and may include an ignition source and/or ignition device and which monitors the operation of fuel burners

Note 1 to entry: The various functions of the system may be in one or more housings.

3.4

burner port

~~any~~ opening in a burner head through which gas or gas-air mixture is discharged for ignition

3.5

combustible material

item capable of ~~combustion~~ being ignited and burned

Note 1 to entry: Such materials ~~shall be~~ are considered combustible even though flame-proofed, fire-retardant treated, or plastered.

Note 2 to entry: When pertaining to materials adjacent to, or in contact with, heat-producing appliances, vent connectors, flue gas vents, steam and hot water pipes, and warm air ducts, combustible materials are those materials made of or surfaced with wood, compressed paper, plant fibres, or other materials that are capable of being ignited and burned.

3.6

design pressure

highest pressure that may occur under any and all operating modes, including steady state and transient

3.7

effluent

products of combustion plus the excess air being discharged from gas utilization equipment

3.8
electromagnetic disturbance
EMD

~~any~~ electromagnetic phenomenon that may degrade the performance of a device, equipment or system, or adversely affect living or inert matter

Note 1 to entry: This note applies to the French language only.

3.9
electromagnetic interference
EMI

degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance

Note 1 to entry: This note applies to the French language only.

3.10
electrical equipment

~~general term including~~ material, fittings, devices, appliances, fixtures, apparatus and the like used as part of, or in connection with, an electrical installation

3.11
emergency shutdown
safety shutdown

control system actions, based on process parameters, taken to stop the fuel cell power system and all its reactions immediately to avoid damage to equipment and/or ~~personnel hazards~~ persons

3.12
fuel cell

electrochemical device that converts the chemical energy of a fuel and an oxidant to electrical energy (DC power), heat and other reaction products

[SOURCE: IEC TS 62282-1:2013, 3.43, modified — In the definition, "other" has been added.]

3.13
fuel cell power system

generator system that uses one or more fuel cell module(s) to generate electric power and heat

[SOURCE: IEC TS 62282-1:2013, 3.49]

3.14
fuel compartment

~~cabinet~~ compartments with internal sources of flammable gas/vapour release

3.15
flue gas vent

passageway for conveying vent gas from gas utilization equipment or their vent connectors to the outside atmosphere

Note 1 to entry: See also 3.33.

3.16

heat exchanger

~~vessel in which heat is transferred from one medium to another~~

3.16

gas carrying circuit

assembly of parts of the stationary fuel cell power system that carry or contain supply gas or process gas

3.17

igniter

device which utilizes electrical energy to ignite gas at a pilot burner or main burner

3.18

ignition device

device mounted on or adjacent to a burner for igniting fuel at the burner

EXAMPLE Pilot burners, spark electrodes and hot surface igniters.

3.19

ignition system timings

3.19.1

flame-establishing period

period of time between the signal to energize the fuel flow means and the signal indicating presence of the burner flame

Note 1 to entry: This may be applicable to proof of the ignition source or main burner flame, or both.

3.19.2

ignition activation period

period of time between energizing the main gas valve and deactivation of the ignition means prior to the lock-out time

3.19.3

start-up lock-out time

period of time between the initiation of gas flow and the action to shut off the gas flow in the event of failure to establish proof of the supervised ignition source or the supervised main burner flame. ~~Re-initiating the lighting sequence requires a manual operation~~

3.19.4

purge time

period of time intended to allow for the dissipation of any unburned gas or residual products of combustion

3.19.4.1

pre-purge time

purge time which occurs at the beginning of a burner operating cycle prior to initiating ignition

3.19.4.2

post-purge time

purge time which occurs at the end of a burner operating cycle

3.19.5

recycle time

period of time between the signal to de-energize the gas supply following loss of the supervised ignition source or the supervised flame and the signal to begin a new start-up procedure

3.20

interlock

control to prove the physical state of a required condition and to furnish that proof to the safety related control device which performs the safety shutdown

3.21

lock-out time

period of time between the signal indicating absence of flame and the action to shut off the fuel supply

3.22

main burner

device or group of devices essentially forming an integral unit for the final conveyance of gas or a mixture of gas and air to the combustion zone, and on which combustion takes place to accomplish the function for which the equipment is designed

3.23

manifold

conduit(s) which supplies fluid to or collects it from the fuel cell or the fuel cell stack

[SOURCE: IEC TS 62282-1:2013, 3.70, modified — The notes to entry have been deleted.]

3.24

permissive

condition within a logic sequence that ~~must~~ has to be satisfied before the sequence is allowed to proceed to the next phase

3.25

pilot

small gas flame used to ignite the gas at the main burner

3.25.1

continuous pilot

pilot that burns without turning off throughout the entire time the burner is in service, whether the main burner is firing or not

3.25.2

intermittent pilot

pilot which is automatically lit each time there is a signal for initialization and burns during the entire period that the main burner is firing

3.25.3

interrupted pilot

pilot which is automatically ~~lit each time there is a signal for initialization. The pilot fuel is cut off automatically at the end of the main burner flame-establishing period~~ ignited prior to the admission of fuel to the main burner and which is automatically extinguished when the main flame is established

~~3.25.4~~

~~**proved pilot**~~

~~pilot flame supervised by a primary safety control~~

3.26

process gas

supply gas that has been transformed to a gas containing predominantly hydrogen

3.27

purge

protective operation to remove gases and/or liquids, such as fuel, hydrogen, air or water, from a fuel cell power system

3.28

recovered heat

thermal energy that has been recovered for useful purposes

Note 1 to entry: The recovered heat is measured by determining the temperatures and flow rates of heat recovery fluid (water, steam, air or oil, etc.) entering and leaving the thermal energy recovery subsystem at the interface point of the small fuel cell power system.

3.29

reformer

reactor to produce a hydrogen rich gas mixture from a raw fuel

~~3.28~~

~~**specific gravity**~~

~~ratio of the weight or mass of a given volume of a substance to that of an equal volume of another substance (air for gases, water for liquids and solids) used as a standard, both measured under the same conditions~~

3.30

small fuel cell power system

fuel cell power system with rated electrical output less than 10 kW, and maximum pressure of less than 0,1 MPa (gauge) for fuel and oxidant passages

Note 1 to entry: Replacement subclauses for small fuel cell power systems are given in Annex C.

3.31

state

3.31.1

cold state

state of a fuel cell power system at ambient temperature with no power input or output

3.31.2

operational state

state of a fuel cell power system with substantial electrical active output power available

3.31.3

passive state

state of the fuel cell power system when the fuel and oxidant systems have been purged with steam, air or nitrogen or per manufacturer's instructions

3.31.4

~~**standby**~~ **pre-generation state**

state of a fuel cell power system being at sufficient operating temperature and in such an operational mode, with zero electrical output power, that the fuel cell power system is capable of being promptly switched to an operational state with substantial electrical active output power

3.31.5

steady state condition

<small fuel cell power system> condition when the fluctuation of electric power output is within ± 2 % of rated power output

3.31.6

storage state

state of a fuel cell power system being non-operational and possibly requiring, under conditions specified by the manufacturer, the input of thermal and/or electric energy and/or an inert atmosphere in order to prevent deterioration of the components

3.32

thermal equilibrium conditions

stable temperature conditions indicated by temperature changes of no more than 3 K ~~(5 °F)~~ or 1 % of the absolute operating temperature, whichever is higher between three readings 15 min apart

3.33

supply gas

gas supplied externally to the stationary fuel cell power system

3.34

supply gas circuit

assembly of parts of the stationary fuel cell power system that carry or contain the supply gas between the gas inlet connection and the outlet of the safety shut-off valves

3.35

vent connector

portion of the venting system which connects the flue outlet of gas utilization equipment to the flue gas vent or single-wall metal pipe

3.36

vent gas

products of combustion from gas utilization equipment plus excess air, plus dilution air in the venting system

3.37

vent terminal

vent cap

fitting at the end of the vent pipe that directs the flue products into the outside atmosphere

3.38

ventilation

3.38.1

mechanical ventilation

movement of air and its replacement with fresh air by mechanical means

3.38.2

natural ventilation

movement of air and its replacement with fresh air due to the effects of wind and/or temperature gradients

[SOURCE: IEC 60050-426:2008, 426-03-07]

3.39

venting system

flue gas vent and vent connector if used, assembled to form a continuous open passageway from the flue collar of gas utilization equipment to the outside atmosphere for the purpose of removing vent gases

4 Safety requirements and protective measures

4.1 General safety strategy

The manufacturer shall perform in written form a risk ~~analysis~~ assessment to ensure that:

- a) all reasonably foreseeable hazards, hazardous situations and events and foreseeable misuse throughout the anticipated fuel cell power system's lifetime have been identified ~~(see Annex A for a listing of typical hazards)~~ Annex A provides a list of hazards that have been dealt with in this document ;
- b) the risk for each of these hazards has been estimated from the combination of probability of occurrence of the hazard and of its foreseeable severity;
- c) the two factors which determine each one of the estimated risks (probability and severity) have been eliminated or reduced to a level not exceeding the acceptable risk level ~~as far as practical possible~~ through application of:
 - 1) inherently safe design of the construction and its methods; or
 - 2) guards and protective devices provided
 - i) by passive control of energy releases without endangering the surrounding environment (for example, burst discs, release valves, thermal cut-off devices), or ~~by safety related control functions; and~~
 - ii) by active control of energy (for example, by electronic control equipment included in the fuel cell power system, which enforces adequate countermeasures based on the evaluation of the sensor signal and by safety related control functions);
- d) for residual risks which could not have been reduced by the measures according to ~~1) and 2) c)~~ c), provisions such as labels, warnings, or requirements of special training shall be taken, considering that such measures need to be understood by the persons who are in the area of the hazards.

For functional safety, the required severity level, performance level or the class of control function shall be determined and designed in accordance with:

- 1) IEC 62061 ~~(respectively~~ and, if applicable, ISO 13849-1 or IEC 61508 (all parts) in conjunction with IEC 61511-1 for applications according to IEC 60204-1;
- 2) IEC 60730-1 or ISO 23550 for appliances according to IEC 60335-1, IEC 60950-1, IEC 62368-1 or IEC 62040-1;
- 3) IEC 61508 (all parts) in conjunction with IEC 61511-1 for other applications.

For failure mode and effects analysis (FMEA) and fault tree analysis methods the following standards can be used as guidance:

- IEC 60812;
- SAE J1739;
- IEC 61025.

4.2 Physical environment and operating conditions

4.2.1 General

The fuel cell power system and protective systems shall be so designed and constructed as to be capable of performing their intended function(s) in the physical environment and operating conditions specified in 4.2.2 to 4.2.8.

4.2.2 Electrical power input

The fuel cell power system shall be designed to operate correctly with the conditions of electrical power input specified in the relevant electrical product application standard as given in 4.7 or as otherwise specified by the manufacturer.

4.2.3 Physical environment

The manufacturer shall specify the physical environment conditions for which the fuel cell power system is suitable. Consideration should be given to:

- a) indoor/outdoor use;
- b) the altitude above sea-level up to which the fuel cell power system ~~shall~~ must be capable of operating correctly;
- c) the range of air temperatures and humidity within which the fuel cell power system ~~shall~~ must be capable of operating correctly;
- d) the seismic zone where it may be sited.

4.2.4 Fuel input

The fuel cell power system shall be designed to operate correctly within the composition limits and supply characteristics of the fuels for which its design is intended (for example, pipeline natural gas). ~~In the user's manual, the manufacturer shall specify the composition limits and supply characteristics of the fuels to be used in the fuel cell power system.~~

4.2.5 Water input

The quality and supply characteristics of the water to be used in the fuel cell power systems shall be specified by the manufacturer.

4.2.6 Vibration, shock and bump

The undesirable effects of vibration, shock and bump (including those generated by the machine and its associated equipment and those created by the physical environment) shall be avoided by the selection of suitable equipment, by mounting it away from the fuel cell power system, or by the use of anti-vibration mountings. This does not include the effects of seismic shock, which shall be addressed separately if the manufacturer deems it appropriate for its product (see 4.2.3).

4.2.7 Handling, transportation, and storage

The fuel cell power system shall be designed to withstand, or suitable precautions shall be taken to protect against, the effects of transportation and storage temperatures within a range of $-25\text{ }^{\circ}\text{C}$ to $+55\text{ }^{\circ}\text{C}$ and for short periods not exceeding 24 h at up to $+70\text{ }^{\circ}\text{C}$. Alternative temperature ranges may be specified by the manufacturer.

The fuel cell power system or each component part thereof shall

- a) be capable of being handled and transported safely, and when necessary, be provided with suitable means for handling by cranes or similar equipment,
- b) be packaged or designed so that it can be stored safely and without damage (for example, adequate stability, special supports, ~~etc.~~).

The manufacturer shall specify special means for handling, transportation and storage if required.

4.2.8 System purging

Means shall be provided in fuel cell power systems to purge where, for safety reasons, a passive state is required after shutdown or prior to start-up, as specified by the manufacturer. A suitable purge system utilizing a medium specified by the manufacturer such as, but not limited to, nitrogen, air or steam in a non-hazardous situation within the intended use may be used.

4.3 Selection of materials

4.3.1 All materials shall be suitable for the intended purpose.

4.3.2 When materials used to construct the fuel cell power system are known to pose hazards under certain circumstances, the manufacturer shall implement the measures and provide the information necessary to sufficiently minimize the risk of endangering persons' safety or health.

4.3.3 Asbestos or asbestos-containing material(s) shall not be used in the construction of a fuel cell power system. The use of other hazardous substances such as lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl, polybrominated diphenyl ether and polychlorinated biphenyl shall be addressed in accordance with national and regional regulations.

Metallic and non-metallic materials used to construct internal or external parts of the fuel cell power system, in particular those exposed directly or indirectly to moisture or that contain process gas or liquid streams, as well as all parts and materials used to seal or interconnect the same, for example, welding consumables, shall be suitable for all physical, chemical and thermal conditions which are reasonably foreseeable within the scheduled lifetime of the equipment and for all test conditions. In particular:

- a) they shall retain their mechanical stability with respect to strength (fatigue properties, endurance limit, creep strength) when exposed to the full range of service conditions and lifetime as specified by the manufacturer;
- b) they shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation;
- c) the chemical and physical properties necessary for operational safety shall not be significantly affected within the scheduled lifetime of the equipment unless replacement is foreseen;
- d) ~~specifically~~, when selecting materials and manufacturing methods, due account shall be taken of the material's corrosion and wear resistance, electrical conductivity, impact strength, aging resistance, the effects of temperature variations, the effects arising when materials are put together (for example, galvanic corrosion), the effects of ultraviolet radiation, and to the degradation effects of hydrogen on the mechanical performance of a material.

NOTE Guidance to account for the degradation effects of hydrogen on the mechanical performance of a material can be found in ISO/TR 15916, ASME B31.12 and Annex B.

4.3.4 Where conditions of erosion, abrasion, corrosion or other chemical attack may arise, adequate measures shall be taken to:

- a) minimize that effect by appropriate design, for example, additional thickness, or by appropriate protection, for example, use of liners, cladding materials or surface coatings, taking due account of the intended and reasonably foreseeable use;
- b) permit replacement of parts which are most affected;
- c) draw attention, in the **maintenance** instructions referred to in 7.4.5, to the type and frequency of inspection and maintenance measures necessary for continued safe use; where appropriate, it shall be indicated which parts are subject to wear and the criteria for replacement.

4.4 General requirements

4.4.1 In so far as their purpose allows, accessible parts of the fuel cell power system shall have no sharp edges, no sharp angles and no rough surfaces likely to cause injury.

4.4.2 The fuel cell power system, or parts of it where there is a reasonable expectation of access, shall be designed and constructed to prevent persons slipping, tripping or falling on or off these parts.

4.4.3 The fuel cell power system, components and fittings thereof shall be so designed and constructed that they are stable enough, under the foreseen operating conditions (if necessary taking climatic conditions into account) for use without risk of overturning, falling or unexpected movement. Otherwise, appropriate means of anchorage shall be incorporated and indicated in the instructions.

4.4.4 The moving parts of the fuel cell power system shall be designed, built and laid out to avoid hazards or, where hazards persist, fixed with guards or protective devices in such a way as to prevent all risk of contact which could lead to accidents.

4.4.5 The various parts of the fuel cell power system and their linkages shall be so constructed that, when used normally, no instability, distortion, breakage or wear likely to impair their safety can occur.

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

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

4.4.8 All safety shutdown system components, whose failure may result in a hazardous event, as identified by the risk analysis assessment noted in 4.1, shall be recognized, certified or separately tested for their intended usage in compliance with the relevant standard considering the intended use.

~~**4.4.9** The fuel cell power system shall be so designed, constructed and/or equipped that risks due to gases, liquids, dust or vapours released during the operation or maintenance of a fuel cell power system, or used in its construction can be avoided.~~

4.4.9 The manufacturer shall take steps to eliminate any risk of injury caused by contact with, or proximity to, external surfaces of the fuel cell power system enclosure, handle, grips or knobs at high temperatures.

4.4.10 If external surfaces of the fuel cell power system's enclosure, handles, grips, knobs or similar parts may be contacted by users without personal protective equipment, the manufacturer shall either limit the temperature of these surfaces at all times according to Table 1 or the manufacturer shall fix guards or protective devices in such a way as to prevent risk of contact that could lead to accidents.

Table 1 – Allowable surface temperature rises

Part	Temperature rise °C K
External enclosures, except handles held in normal use	60
Surfaces of handles, knobs, grips and similar parts which are held for short periods only in normal use	
– of metal	35
– of porcelain	45
– of moulded material (plastic), rubber or wood	60
<p>NOTE 1 The values in the table are the maximum surface temperature rises above ambient of external surfaces that may can be contacted during operation by people without personal protective equipment. The above values are referenced in Table 3 of IEC 60335-1:2010 2016.</p> <p>NOTE 2 The values in the table are based on an ambient temperature not normally exceeding 25 °C 298,15 K but occasionally reaching 35 °C 308,15 K. However, the temperature rise values specified are based on 25 °C 298,15 K.</p>	

The temperatures on walls, floor and ceiling adjacent to a stationary fuel cell power system shall not exceed 50 °C above ambient temperature under the test conditions of 5.12 b).

4.4.11 The fuel cell power system shall be so designed and constructed that the emission of airborne noise is reduced to a level suited for the intended use or location in compliance with applicable regional or national airborne noise codes and standards.

4.4.12 The fuel cell power system exhaust to atmosphere, under normal steady-state operating conditions, shall not contain ~~concentrations~~ volume fraction of carbon monoxide in excess of 0,03 % by volume in an air-free sample of the effluents, which is a sample that has its effluent carbon monoxide (CO) ~~concentration~~ volume fraction mathematically corrected as though there was zero percent excess air.

The CO ~~concentration~~ volume fraction of the dry, air-free combustion products is given by the formula

$$CO = (CO)_{avg} \times (CO_2)_{max} / (CO_2)_{avg}$$

where

CO is the carbon monoxide concentration of air-free combustion products in percent;

(CO₂)_{max} is the maximum carbon dioxide concentration of the dry, air-free combustion products for test fuel in percent;

(CO)_{avg} and (CO₂)_{avg} are the average values of measured concentrations in the sample taken at least 3 times during the test, both expressed in percent;

or

$$CO = (CO)_{avg} \times (21 \%) / (21 \% - (O_2)_{avg})$$

where

(CO)_{avg} and (O₂)_{avg} are the average values of measured concentrations in the sample taken at least 3 times during the test, both expressed in percent.

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

4.4.14 The maximum temperatures of components and materials, as installed in the fuel cell power system, shall not exceed their temperature ratings.

4.4.15 The manufacturer shall give consideration to the suitability of the fuel cell power system to operate where contaminants (for example, dust, salt, smoke, and corrosive gases) are present in the physical environment.

4.4.16 The fuel cell power system enclosure shall be designed to safely contain any anticipated hazardous liquid leaks (see 4.5.2 f) for liquid fuel. The containment means shall have a capacity of 110 % of the maximum volume of fluid anticipated to leak.

4.4.17 The manufacturer shall take measures to ensure against condensate accumulation. The manufacturer shall take measures to ensure that vent gas does not escape through condensate drain lines.

4.5 Pressure equipment and piping

4.5.1 Pressure equipment

Pressurized vessels, such as reactors, heat exchangers, gas-fired tube heaters and boilers, electric boilers, coolers, accumulators and similar containers, and associated pressure relief mechanisms, such as relief valves and similar devices, shall be constructed and marked in accordance with applicable regional or national pressure equipment codes and standards.

Vessels such as tanks and similar containers that fall outside the scope of national pressure equipment standards shall be constructed of suitable materials in accordance with 4.3 and shall meet the applicable requirements of 4.4. Such vessels, and their related joints and fittings, shall be designed and constructed with adequate strength for functionality and leakage resistance to prevent unintended releases.

Hydrogen stored in metal hydrides assemblies shall comply with ISO 16111.

4.5.2 Piping systems

Piping and its associated joints and fittings shall conform to the applicable clauses of ISO 15649.

Piping systems designed for internal gauge pressure at or above zero but less than 105 kPa, handling fluids that are non-flammable, non-toxic and not damaging to human tissue and having a design temperature from –29 °C through 186 °C are not included in the scope of ISO 15649. Piping systems under these conditions shall be constructed of suitable materials in accordance with 4.3 and shall meet the applicable requirements of 4.4. Such pipes, and their related joints and fittings, shall be designed and constructed with adequate strength for functionality and leakage resistance to prevent unintended releases.

The design and construction of both rigid and flexible pipes and fittings shall consider the following aspects.

- a) Materials shall meet the requirements specified in 4.3.
- b) The internal surfaces of piping shall be thoroughly cleaned to remove loose particles and the ends of piping shall be carefully reamed to remove obstructions and burrs.
- c) If fluid condensate or sediment accumulation inside gaseous fluid piping could cause damage from water hammer, vacuum collapse, corrosion and uncontrolled chemical reactions during start-up, shutdown and/or use, the manufacturer shall provide means for drainage and removal of deposits from low areas and for access during cleaning, inspection and maintenance. In particular, the manufacturer shall take measures to ensure against sediment or condensate accumulation in fuel gas controls. Sediment traps or filters shall be installed or adequate guidelines shall be provided in the products technical documentation.

- d) The manufacturer shall take measures to ensure against sediment accumulation in liquid fuel controls. Sediment traps or filters shall be installed or adequate guidelines shall be provided in the technical documentation of the product.
- e) Non-metallic piping used to convey combustible gases shall be protected against the possibility of overheating and mechanical damage. Measures as required by the risk ~~analysis~~ assessment specified in 4.1 shall be provided to prevent the temperature of components conveying combustible gases from surpassing their design temperatures.
- f) Liquid fuel cell power systems shall include provisions for capturing, recycling or safe disposal of released liquid fuel. Drip pans, spill guards, or double-walled pipe shall be designed to prevent uncontrolled releases.

4.5.3 Flue gas venting systems

The fuel cell power system shall be provided with a venting system to convey products of combustion from fuel utilization equipment to the outside atmosphere. The manufacturer shall either supply a vent pipe system that meets the requirements, or provide in the product's technical documentation adequate instructions to allow selection of a vent pipe system meeting these requirements.

- a) Materials shall meet the requirements specified in 4.3. In particular, the venting system shall be constructed of material resistant to corrosion by condensate. Non-metallic material shall be judged on its temperature limitation, strength and resistance to the action of condensate.
- b) The venting system parts of a fuel cell power system shall be durable. Venting system parts, including parts within the fuel cell power system, shall not break, disassemble or become damaged to the extent that they permit unsafe fuel cell power system operation.
- c) The vent pipe shall be properly supported and shall be provided with a rain cap or other feature that would not limit or obstruct the gas flow from venting.
- d) Means, such as drainage, shall be provided to prevent water, ice and other debris from accumulating inside the vent pipe or obstructing the vent pipe.
- e) A venting system for a fuel cell power system shall be leak-tight.
- f) The exhaust outlet collar shall be of such size as to accommodate a vent connector that is commercially available or to accommodate a conduit as specified in the manufacturer's installation instructions.
- g) Pressure switches used to prove exhaust gas flow, if used, shall be factory set, or at the manufacturer's discretion, be set by ~~authorized~~ service personnel at the construction site. The adjustment means shall then be secured. A pressure switch shall bear a marking indicating clearly the appliance manufacturer's or distributor's part number or appropriate documentation which correlates to the locked pressure setting.
- h) Parts of a pressure switch in contact with exhaust gas condensate shall be corrosion-resistant to exhaust gas condensate at the normal operating temperatures.
- i) The fuel cell power system shall be capable of starting up and then shall operate with the appropriate carbon monoxide (CO) level when the venting system is exposed to up to 116 Pa static pressure or up to 134,5 Pa velocity pressure (from 9 km/h to 54 km/h wind velocity) according to the tests in 5.13.
- j) When the fuel cell power system is provided with a venting system, the temperature of the exhaust gases conveyed by that venting system shall not exceed temperatures acceptable for the materials used to construct the venting system.
- k) The venting system length shall be within the limits bounded by the testing carried out in Clause 5.

4.5.4 Gas-conveying parts

The gas-conveying parts shall ~~comply with the following condition:~~

~~the gas passage shall~~ be gas-tight such that the tightness ~~shall not~~ cannot be undermined under ordinary transportation, installation and use.

There are no external leakage requirements for parts or segments of the gas circuit that operate at all operating conditions below ambient air pressure.

If a control function ensures that a gas circuit operates below ambient air pressure, then the measures to ensure safety shall comply with the requirements as given in the relevant application standard as specified in 4.1.

4.6 Protection against fire or explosion hazards

4.6.1 Prevention against fire and explosion hazards in fuel cell power systems provided with ~~cabinets~~ enclosures

For parts of the gas carrying circuit where the internal gas pressure is above the ambient air pressure, the following applies.

- a) The integrated systems of the fuel cell power system shall be assembled so as to prevent hazards associated with flammable atmosphere accumulations within the fuel cell power system.
- b) The boundary for dilution of normal internal releases to below 25 % of the lower flammability limit (LFL) may be determined by computational fluid dynamic analysis, tracer gas, or similar methods, such as those given in IEC 60079-10-1. All devices installed within dilution boundaries shall meet the requirements specified in 4.6.1 e). The volume within dilution boundaries shall be classified according to IEC 60079-10-1. The LFL of typical gases are provided in IEC 60079-20-1.

NOTE 1 Examples of normal internal releases are fuel cell stack leak at the seals without a fault condition and do not include leak tight components. See 4.6.1 g) 2).

- c) ~~Cabinet compartments~~ Enclosures with internal sources of flammable gas/vapour release are defined as fuel compartments. Fuel compartments shall be designed to
 - 1) maintain gas mixtures below 25 % (LFL), except in dilution boundaries, and
 - 2) limit the extent of dilution boundaries to within the fuel compartment.
- d) Methods to maintain normal internal releases below 25 % (LFL), except in dilution boundaries, include the following.

1) Controlled oxidation of normal internal releases

This may be accomplished by the provision of a continuous and reliable ignition and oxidant sources that ensures the combustion of the released gases or the utilization of catalytic oxidation units.

The manufacturer shall ensure that the maximum credible release, when reacted, produces pressures and temperatures that can be contained within the fuel compartment and tolerated by the components exposed to such conditions.

2) Air dilution of normal internal releases

This may be accomplished by the provision of mechanical ventilation to dilute with air the concentration of normal releases to less than 25 % (LFL), except within dilution boundaries. In all cases, the minimum ventilation rate shall be consistent with the allowable leakage rate test given in 5.4.

Ventilated fuel compartments shall be designed to operate at negative pressure relative to other types of compartments in the fuel cell power system and its surroundings. This negative pressure in the fuel compartment is established by means such as induced or exhaust ventilation. Proper operation of the ventilation system shall be confirmed by measuring either flow or pressure. Failure of ventilation shall cause a shutdown of the process equipment. Control functions to ensure this ventilation shall be according to the standard for functional safety as given in 4.1. Alternatively, fuel compartments of fuel cell power systems need not be ventilated at negative pressures if adequate means are provided to limit the concentration of flammable gas below 25 % of the LFL under all conditions of use except within dilution boundaries or as described in 4.6.1 g).

Fuel compartments that rely on ventilation for protection against accumulation of flammable atmospheres shall be purged in such a way that the atmosphere will be brought below 25 % of the LFL.

NOTE 2 One method of accomplishing this is with at least four air exchanges within an appropriate time interval to ensure this result.

The purging will take place prior to the energization of any devices that are not suitable for the area classification according to 4.6.1 b). Purging is not required if the atmosphere within the compartment and associated ducts can be demonstrated by design to be non-hazardous. All devices, which shall be energized prior to purging or in order to accomplish purging, shall meet the requirements specified in 4.6.1 e).

- e) Within areas classified as hazardous in 4.6.1 b), except for units that use the protection method described in 4.6.1 d) 1), the manufacturer shall eliminate ignition sources by ensuring that the
 - 1) installed electrical equipment is suitable for the area classification according to ~~IEC 60079-0 and other applicable parts of the IEC 60079 series~~ IEC 60079-10-1;
 - 2) installed electrical resistance trace heating, if available, complies with IEC/IEEE 60079-30-1;
 - 3) surface temperatures do not exceed 80 % of the auto-ignition temperature, expressed in degrees Celsius, of the flammable gas or vapour. See IEC 60079-20-1 for guidance regarding auto-ignition temperatures of various flammable fluids;
 - 4) equipment containing materials capable of catalysing the reaction of flammable fluids with air shall be capable of suppressing the propagation of the reaction from the equipment to the surrounding flammable atmosphere;
 - 5) potential for static discharge has been eliminated by proper bonding and grounding, and by proper material selection.
- f) Compartments that contain electrical or mechanical equipment shall be maintained at positive pressure relative to adjacent compartments with sources of flammable gas or vapour according to IEC 60079-2, unless the equipment meets the requirements specified in 4.6.1 e).
- g) The fuel cell power system shall be provided with passive and active means, or a combination thereof, to maintain abnormal internal releases below 25 % (LFL), except in dilution boundaries.

NOTE 3 Abnormal internal releases include gas leakage under fault conditions, e.g. a pressure relief valve releasing gas into the space of the fuel cell appliance.

- 1) Sudden and catastrophic failures need not be considered a release scenario in this analysis when protection against such failures has already been contemplated in the pressure equipment and piping design (see also 4.5).
- 2) Parts of the gas carrying circuit which comply with the following need not be considered as potential leak sources:
 - i) according to ISO 23550, or
 - ii) solid piping which is designed according to the design rules noted in 4.5.
- 3) "Passive" means include, but are not limited to, the mechanical limitation of releases of flammable gases or vapours to a maximum value by using pipe orifices and similar methods of flow restriction or joints permanently secured and so constructed that they limit the release rate to a predictable maximum value.
- 4) "Active" means may include flow measurements and controls or the provision of safety devices such as combustible gas sensors. These means shall meet the requirements specified in 4.9, and shall cause a fuel cell power system shutdown upon occurrence of conditions under which the concentration of any flammable gas in the ventilation exhaust exceeds 25 % of the LFL of that gas.
- h) The fuel cell power system shall be designed for the safe dispersal of the ventilation and process exhaust streams. In particular, for indoor installations the ventilation and process exhaust shall be designed for connection to a flue or venting system.

- i) Potential for static discharge ~~has been~~ shall be eliminated by proper bonding and grounding of metallic parts by selecting materials that do not generate charges which could result in a spark capable to ignite an ignitable gas/air mixture. The effect of flow rates within pipes generating possible charges shall also be considered.
- j) A control function whose purpose is to avoid exceeding 25 % of the LFL by, for example, dilution with air and/or measuring the concentration and shut-off if exceeding the limit, shall be designed according to the requirements specified in 4.1.

NOTE 4 Non-metallic tubing carrying hydrogen gas ~~may~~ can accumulate electrostatic charge along its surface. Discharges from the surface of this tube ~~may~~ can be sufficient to ignite a flammable mixture of gas or vapour in the surrounding environment. IEC 60079-10-1 addresses measures to eliminate electrostatic discharges in Zones 1 and 2. This ~~may~~ can be achieved by specifying a tube material with sufficient conductivity, or by limiting gas flow velocity to values below which electrostatic charge does not accumulate. Tubing that relies on a protective system to eliminate electrostatic discharge (e.g. a grounding wire or braid) is not addressed in IEC 60079 (all parts) for Zone 0 locations.

NOTE 5 Metal braid coverings, or conductive wires within the non-metallic tubing wall ~~may~~ can increase the chance of electrostatic discharge if those conductors become disconnected from their bonding conductor. Positively securing bonding and grounding conductors in Zones 1 and 2 by mechanical means addresses this issue.

4.6.2 Prevention of fire and explosion hazards in burners

- a) Fuel cell power systems shall be designed in such a way that the unsafe build-up of flammable or explosive gases in burners (start, main and auxiliary burners of a reformer section, tail gas burners) is avoided.
- b) The main burner shall be fitted with a pilot or a device for direct ignition.
- c) The direct ignition device shall be controlled automatically and shall not cause deterioration of the burner. Direct ignition devices shall be positively positioned with respect to the main burner ports. Means shall be provided to prevent incorrect assembly or reversible mounting of any direct ignition device in relation to the burner being served.
- d) Pilots shall be controlled automatically and direct ignition shall light any pilot fuel. Pilots shall be designed and fitted in such a way that they are located correctly in relation to the burners that they ignite. When a pilot is an integral part of the start burner, it need be evaluated only under the construction and performance specifications of this document.
- e) An automatic electrical burner control system shall comply with requirements specified in 4.9.2 and shall be fitted to the burner to ensure safe start-up, operation and shutdown including lock-out if required. Flame or oxidation monitoring is an integral function of this control.
- f) The main burner or pilot flame, or both, shall be supervised by a flame detector or other adequate means. If a main burner is ignited by a pilot, the presence of flame at the pilot shall be detected before gas is released to the main burner. A system having an interrupted pilot shall provide supervision of the main burner flame following the main burner flame-establishing period.
- g) The supervised pilot flame shall be capable of effectively igniting the fuel at the main burner even when the fuel supply to the pilot is reduced to the point where the pilot flame is just sufficient to actuate the flame supervision according to IEC 60730-2-5.
- h) If the heat input of a pilot does not exceed 0,250 kW, there is no requirement for the flame establishing period.
- i) If the heat input of a pilot exceeds 0,250 kW, or in case of direct ignition of the main burner, the start-up lock-out time is determined by the manufacturer so that, in accordance with the delayed ignition test (5.10.2.8), no health or safety hazard for the user or damage to the fuel cell power system occurs.
- j) Each pilot or direct main burner ignition attempt begins with the opening of the fuel valves and ends with the closing of the fuel valves. The spark shall continue at least until ignition occurs or until the end of the flame-establishing period.
- k) Pilot or direct main burner ignition shall be attempted a maximum of three times, each time followed by recycling of the burner control system. A higher number of attempts shall be determined by the manufacturer on the basis of a safety analysis.

An absence of flame at the end of the third attempt shall result in, at least, a lock-out.

- l) In case of flame failure, the system shall cause at least re-ignition, recycling or lock-out.
- m) The pilot or main burner flame failure lock-out time shall not exceed 3 s. A longer lock-out time is acceptable as determined by the manufacturer on the basis of a safety analysis.

Exception: The primary safety control need not de-energize all fuel safety valves if the temperature of the burner cavity **surfaces** with which the flammable air/fuel mixture is in contact exceeds the auto-ignition temperature of the fuel, ~~measured in °C~~. See also 4.6.2 x).

- n) If re-ignition takes place, under the test conditions of 5.10.2, the direct ignition device shall be re-energized within a maximum time of 1 s after the disappearance of a flame signal. In this case, the flame-establishing period is the same as is used for ignition and starts when the ignition device is energized. An absence of flame at the end of the flame-establishing period shall result in, at least, a lock-out.
- o) If recycling takes place, under the test conditions of 5.10.2, this shall be preceded by an interruption of the gas supply and purging; the ignition sequence shall restart from the beginning. In this case the flame-establishing period is the same as is used for ignition and starts when the ignition device is energized. Recycling shall be attempted a maximum of three times, each time followed by purging. An absence of flame at the end of the third attempt shall result in, at least, a lock-out.
- p) An automatic electrical burner control system, as defined in IEC 60730-2-5, shall be arranged to prevent feedback by a motor, capacitor or similar device from energizing a fuel valve or ignition device after a control function ~~s~~ to shut off the main burner.
- q) When, for safety reasons, a passive state is required prior to start-up or after shutdown, means shall be provided to automatically purge a burner housing or enclosure of any flammable gas mixture before the trial for ignition at the start and in between recycling trials. This purge shall provide a minimum of four air changes in the combustion chamber. The ~~amount of~~ air purged shall be monitored by a safety related control function. The level of safety shall be based on the risk ~~analysis~~ **assessment** according to 4.1.
- r) Automatic burner control system components shall be installed so the operation of these devices and main burner ignition will not be affected by falling particles or condensation during normal operation.
- s) When primary air under pressure is mixed with the fuel supply, effective means shall be provided to prevent air from passing back into the fuel line, or fuel into the air supply. The fuel and air supply shall be suitably controlled to prove air flow prior to ignition and to prevent fuel from entering each reformer burner until the air supply is available and, in the event of air fan failure, to shut off the fuel supply.
- t) Mechanical linkage for operating the fuel and air controls, if used, shall be designed to reliably maintain the correct fuel/air ratio and to resist accidental breakage and disengagement.
- u) Upon shutdown, hazardous gases in the process system shall be safely contained, purged or reacted.
- v) The manufacturer shall provide the fuel cell power system with adequate means to prevent the crossing of air into fuel or combustible process gas lines or of fuel or combustible process gas into air lines.
- w) The fuel cell power system under a blocked outlet condition shall not produce a concentration of carbon monoxide in excess of 0,03 % in an air-free sample of the effluents, or as specified in national regulations, according to the test of 5.15.2.2. Additionally, the fuel cell power system shall not produce a carbon monoxide concentration in excess of 0,03 % in an air-free sample of the effluents when the air supply inlet is blocked according to the test of 5.15.2.3.
- x) If the temperature of the combustion compartment and the parts of the combustion compartment directly in touch with the gas/air mixture is above the auto-ignition temperature (measured in °C), flame supervision may be substituted by the temperature monitoring. If the temperature drops below the auto-ignition temperature the safety shut-off valves shall be de-energized. Furthermore, the release of gas flow shall only ~~be~~

~~released~~ occur after the self-ignition temperature is ensured. The control function shall be based on the safety level given in IEC 60730-2-5.

4.6.3 Prevention of fire and explosion hazards in catalytic fuel oxidation systems (catalytic burners)

- a) Within fuel cell power system components carrying fluids in which flammable or explosive gas volumes are intentionally produced to conduct a controlled catalytic fuel oxidation reaction (for example, catalytic partial oxidation, catalytic combustion), the manufacturer shall avoid the unsafe build-up of flammable or explosive gases.
- b) When, for safety reasons, a passive state is required prior to start-up or after shutdown, means shall be provided to purge the catalytic fuel oxidation system components. The purging system may utilize a medium specified by the manufacturer such as, but not limited to, nitrogen, air or steam. The extent of purging is determined by considering flow characteristics, system dynamics and geometry. The ~~amount of~~ purge gas shall be monitored by a safety related control function. The level of safety shall be based on the risk ~~analysis~~ assessment according to 4.1.
- c) Where air is mixed with fuel, the manufacturer shall provide adequate means to prevent air from flowing back into the fuel line, or fuel into the air supply.
 - 1) For air-rich systems
The fuel and air supply shall be suitably controlled to provide air prior to reaction initiation, and to prevent fuel from entering the reactor until the air supply is available.
 - 2) For fuel-rich systems
The fuel and air supply shall be suitably controlled to provide fuel prior to reaction initiation, and to prevent air from entering the reactor until the fuel is available.
- d) Mechanical linkage for operating the fuel and air controls, if used, shall be designed to reliably maintain the correct fuel-air ratio and to resist accidental breakage and disengagement.
- e) The reaction initiation time shall be determined by considering the response time of the system control devices and the time required to build up the maximum allowable quantity of flammable or explosive mixture that can safely be contained in the system based on flow rates, fuel-air mixture flammability and system dynamics and geometry.
- f) If the catalytic reaction is not established within the reaction initiation time, the system shall automatically shut off the fuel supply or, for fuel-rich operations, the supply of all reactants.
- g) The temperature of the catalyst shall be monitored either directly or indirectly. The reaction fails if the temperature or rate of temperature change of the catalyst falls outside the acceptable range specified by the manufacturer. Then the system shall automatically shut off the fuel supply, or for fuel-rich operations, the supply of all reactants. The reaction failure lock-out time shall not exceed 3 s. A longer lock-out time is acceptable as determined by the manufacturer on the basis of a safety analysis.
- h) If a mixture of fuel and air could potentially build up inside the fuel cell power system following either the failure of a reaction to start within the reaction initiation time, or the extinction of a reaction, or decrease or increase of the reaction rate to unsafe levels, the manufacturer shall ensure that the maximum quantity of flammable mixture that could credibly accumulate, if combusted, produces pressures and temperatures that can be contained within the components exposed to such conditions.
- i) Upon shutdown, hazardous gases in the process system shall be safely contained or disposed.
- j) Where air and fuel streams are put in close contact as part of the thermal management system, the manufacturer shall provide the fuel cell power system with adequate means to prevent health or safety risks from arising from the crossing of air into fuel lines or of fuel into air lines.

NOTE Subclause 4.6.3 is also applicable to the anode exhaust catalytic reactor.

4.7 Electrical safety

The electric system design and construction, as well as the application of the electric and electronic equipment, including electric motors and enclosures, shall meet the requirements of the relevant electrical product application standard; for example:

- a) IEC 60335-1 (e.g. residential, commercial and light industrial);
- b) IEC 60204-1 (e.g. large industrial);
- c) IEC 60950-1 or IEC 62368-1 (e.g. telecom);
- d) IEC 62040-1 (e.g. UPS).

Voltages above the 600 V limit are permissible when separately evaluated to standards appropriate to the higher voltage.

NOTE 1 IEC 60204-1 limits this requirement to those components that are relied upon to perform a direct safety function (gas detector, safety shut-off valve, fan interlock), or would present a safety hazard (fire, shock, burn) if they were to fail. The latter is determined through the safety analysis of 4.1. Electrical components for which there is no applicable standard can meet the requirements for electrical isolation, creepage and clearance, leakage currents, overcurrent protection, as well as grounding and bonding that are found in IEC 60950-1 or IEC 62368-1 or basic publications or group safety publications.

NOTE 2 In some cases, the system integrator can design unique electrical components or a circuit board assembly for which no standard is currently available. In that case, design requirements for electrical safety are found in IEC 60950-1 or IEC 62368-1 or basic safety publications or group safety publications.

The selection of the appropriate application will be provided in the technical specification.

The fuel cell designer shall also consider the following fuel cell specific issues:

- a) residual charge on the fuel cell stack;
- b) energy hazard between cells.

4.8 Electromagnetic compatibility (EMC)

The fuel cell power system shall not generate electromagnetic disturbances above the levels appropriate for its intended places of use. In addition, the equipment shall have an adequate level of immunity to electromagnetic disturbances so that it can operate correctly in its intended environment. As applicable, the fuel cell power system shall comply with the following standards: IEC 61000-3-2, IEC 61000-3-3, IEC TS 61000-3-4, IEC TS 61000-3-5, IEC 61000-3-11, IEC 61000-6-1, IEC 61000-6-2, IEC 61000-6-3, and IEC 61000-6-4.

4.9 Control systems and protective components

4.9.1 General requirements

4.9.1.1 The risk ~~analysis~~ assessment as specified in 4.1 shall provide the basis to set the protection parameters of the safety circuit.

4.9.1.2 The fuel cell power system shall be designed in such a way that the single failure of a component does not cascade into a hazardous condition. Means to prevent cascade failures include, but are not limited to,

- a) protective devices in the fuel cell power system (for example, interlocking guards, trip devices),
- b) protective interlocking of the electrical circuit,
- c) use of proven techniques and components,
- d) provision of partial or complete redundancy or diversity, and
- e) provision for functional tests.

The evaluation of the required measures to avoid and/or control failures if they occur are given in the application relevant control standards as shown in 4.1.

4.9.2 Control systems

4.9.2.1 General requirements

Automatic electrical and electronic controls of fuel cell power systems shall be designed and constructed so that they are safe and reliable. Residential, commercial and light industrial fuel cell power systems shall conform to IEC 60730-1.

Automatic electrical burner control systems shall comply with IEC 60730-2-5.

Automatic electrical control systems for catalytic oxidation reactors shall comply as applicable with IEC 60730-2-5. Specific requirements are provided in 4.6.3.

Manual controls shall be clearly marked and designed to prevent inadvertent adjustment and activation.

In particular, the following requirements apply.

4.9.2.2 Start

The start of an operation shall be possible only when all the safeguards are in place and are functional.

Suitable interlocks shall be provided to secure correct sequential starting.

It shall be possible for automated plant functioning in automatic mode to be restarted after a stoppage only after the safety conditions have been fulfilled. It shall also be possible to restart the fuel cell power system by intentional actuation of a control provided for the purpose, provided such restarting is verifiably non-hazardous.

This requirement does not apply to the restarting of the fuel cell power system resulting from the normal sequence of an automatic cycle.

4.9.2.3 Shutdowns

4.9.2.3.1 General

As determined by the risk ~~analysis~~ assessment indicated in 4.1, the functional requirements of the fuel cell power system shall be provided with the following shutdowns:

- Emergency shutdowns

An emergency shutdown is, for air-rich operation, the de-energization of the main fuel flow means, or for fuel-rich operation, the de-energization of both the process air flow and the main fuel flow means, as the result of the action of a limiter, a cut-out or the detection of an internal fault of the system.

- Normal shutdown

A normal shutdown is, for air-rich operation, the de-energization of the main fuel flow means, or for fuel-rich operation, the de-energization of both the process air flow and the main fuel flow means, as the result of the opening of a control loop by a control device ~~such as a thermostat~~. The system returns to the start position.

4.9.2.3.2 Emergency shutdowns

a) General

Emergency shutdowns shall be incorporated as part of the fuel cell power system in order to avert actual or impending danger that cannot be corrected by controls. These functions shall

- 1) stop the dangerous condition without creating additional hazards,
- 2) trigger or permit the triggering of certain safeguard actions where necessary,
- 3) override all other functions and operations in all modes,
- 4) prevent reset from initiating a restart,
- 5) be fitted with restart lock-outs in such a way that a new start command may take effect on normal operation only after the restart lock-outs have been intentionally reset.

b) Emergency stop

Manual emergency shutdowns (i.e. emergency stops), if required by the risk ~~analysis~~ **assessment** in 4.1, shall have clearly identifiable, clearly visible and quickly accessible controls in accordance with ISO 13850.

c) Control functions in the event of control systems failure

In case of fault in the control system logic or failure of, or damage to, the control system hardware,

- 1) the fuel cell power system shall not be prevented from stopping once the stop command has been given,
- 2) automatic or manual stopping of the moving parts shall be unimpeded,
- 3) the protection devices shall remain fully effective,
- 4) the fuel cell power system shall not restart unexpectedly.

When a protective device or interlock causes a safety shutdown of the fuel cell power system, that condition shall be signalled to the logic of the control system. The reset of the shutdown function shall not initiate any hazardous condition. Control **and/or** monitoring systems that can operate safely in the hazardous situation may be left energized to provide system information.

4.9.2.3.3 Normal shutdown

Upset conditions that can be safely controlled or that do not pose immediate danger may be corrected with a normal shutdown. A normal shutdown may remove all power to the equipment, or may leave power available to the fuel cell power system actuators.

4.9.2.4 Permissives

Permissives shall be implemented consistent with requirements established from the risk ~~analysis~~ **assessment** described in 4.1.

4.9.2.5 Complex installations

When the fuel cell power system is designed to work together with other equipment, the fuel cell power system shutdown function, including the emergency stop, shall be provided with means, such as signal interfaces, to enable the coordinated shutdown with equipment upstream and/or downstream, as applicable, of the fuel cell power system if continued operation can be dangerous.

4.9.2.6 Operating modes

a) Fuel cell power systems operating modes include

- 1) an operational state (substantial electrical output power), and
- 2) a ~~standby~~ **pre-generation** state (zero net power output).

Non-operating modes can include

- a cold state,
 - a passive state, and
 - a storage state.
- b) There shall be two primary transitions: start-up and shutdown:
- 1) start-up is the transition from NON-OPERATING to OPERATING MODE and shall be initiated from an external signal;
 - 2) shutdown is the automatic transition from OPERATING to NON-OPERATING MODE. It may be initiated either via an external signal, or internal signal in response to out of limits conditions to the fuel cell power system controller.
- c) Secondary operating modes and transitions may be provided as necessary, such as to allow for different power output rates or for adjustment, maintenance or inspection activities.
- d) Mode selection
- If the fuel cell power system has been designed and built to allow for its use in several control or operating modes presenting different safety levels (for example, to allow for adjustment, maintenance, inspection, etc.), it shall be capable of mode selection that can be secured in each position. Each position of the selector shall correspond to a single operating or control mode and shall be fitted with restart lock-outs. A new start command may take effect on normal operation only after the restart lock-outs have been intentionally reset. Mode selection shall be allowed by any securable means, such as a positioning knob, key lock, or software command, to prevent unintentional change to a different mode that may lead to a hazardous condition. The selector may be designed to restrict user access to certain fuel cell power system operating modes (for example, access codes for certain numerically controlled functions, ~~etc.~~).
- e) The mode selected shall override all other control systems with the exception of the safety shutdowns.

4.9.2.7 Remote monitoring and control systems

Fuel cell power systems that can be operated remotely shall have a local, labelled switch or other means to disconnect the fuel cell power system from remote signals that may be used while a local operator performs inspection or maintenance. Remote monitoring and control systems shall

- a) be allowed on fuel cell power systems only where remote control will not lead to an unsafe condition,
- b) not override locally set protective safety controls.

4.9.3 Protective components

4.9.3.1 General

Suitable protective devices, and combinations thereof, comprise adequate monitoring devices such as indicators and/or alarms which enable adequate action to be taken either automatically or manually to keep the fuel cell power system within the allowable limits.

Protective devices shall

- a) be ~~so~~ designed and constructed so as to be reliable and suitable for their intended duty and take into account the maintenance and testing requirements of the devices, where applicable;
- b) have their protective functions independent of other possible functions;
- c) comply with appropriate design principles in order to obtain suitable and reliable protection. These principles include, in particular, fail-safe modes, redundancy, diversity and self-diagnosis.

Dangerous overloading of equipment shall be prevented at the design stage by means of integrated measurement, regulation and control devices, such as over-current cut-off switches, temperature limiters, differential pressure switches, flow-meters, time-lag relays, over-speed monitors and/or similar types of monitoring devices.

Protective devices with a measuring function shall be designed and constructed so that they can cope with foreseeable operating requirements and special conditions of use. Where necessary, it shall be possible to check the reading accuracy and serviceability of devices. These devices shall incorporate a safety factor that ensures that the alarm threshold lies far enough outside the limits to be registered, taking into account, in particular, the operating conditions of the installation and possible aberrations in the measuring system. If the protective control consists of electronic components then the control shall be designed according to the requirements specified in 4.1.

4.9.3.2 Type of components

The following components shall comply with the appropriate safety related measures as given in the following mentioned standards to ensure the results of 4.1.

- a) Pressure limiting devices, such as pressure switches, shall comply with IEC 60730-2-6.
- b) Temperature monitoring devices shall have an adequately safe response time, consistent with the measurement function, according to IEC 60730-2-9.
- c) A fuel cell power system may elect to use a gas detector as a protective component to mitigate against possible gas leakage. A gas detector, if used in the fuel cell power system, shall comply with ISO 26142, IEC 60079-29-1 or ISO 23550 in conjunction with IEC 60730-1 based on the result of the risk assessment according to 4.1 and the standards specified therein, as appropriate.
- d) A gas sensor control loop (sensing element, electronic circuit, shut-off of the fuel supply) shall be fail safe and designed according to the requirements in 4.1.
- e) All parts of fuel cell power systems which are set or adjusted at the stage of manufacture, and which should not be manipulated by the user or the installer, shall be appropriately protected.
- f) Levers and other controlling and setting devices shall be clearly marked and given appropriate instructions so as to prevent any error in handling. Their design shall be such as to preclude accidental manipulation.

4.10 Pneumatic and hydraulic powered equipment

Pneumatic and hydraulic equipment of fuel cell power systems shall be designed according to ISO 4414 and ISO 4413, respectively.

4.11 Valves

4.11.1 Shut-off valves

- a) Shut-off valves shall be provided for all equipment and systems where containment or blockage of the process fluid flow is necessary during shutdown, testing, maintenance, upset, or emergency conditions.
- b) Shut-off valves shall be rated for the service pressure, temperature, and fluid characteristics.
- c) Actuators mounted on shut-off valves shall be temperature-rated to withstand the local ambient temperature and additional heat conducted from the valve body.
- d) Electrically, hydraulically or pneumatically operated shut-off valves shall be of a type that will move to a failsafe position upon loss of actuation energy.

4.11.2 Fuel valves

Supply fuel valves shall meet the following requirements.

- a) All fuel supplied to the fuel cell power system shall pass through at least two automatic valves, in series, each of which serves as a safety shut-off valve and may serve as an operating control valve.
- b) Any fuel supplied directly to fuel-fired equipment, such as a start-up boiler or a reformer start burner, shall also pass through at least two automatic valves, in series, each of which serves as an operating valve and a safety shut-off valve. These valves may or may not be contained in a single control body.
- c) Electrically operated supply fuel valves shall meet the requirements of ISO 23551-1 or ISO 23553-1 as applicable.
- d) When fuel gases are recycled from appliances using the fuel cell power system output gas, the connection may be exempt from employing shut-off valves if demonstrated to be safe according to the risk-analysis assessment of 4.1.
- e) Flammable gaseous manual shut-off valves shall be suitable for their intended application based on ISO 23550.

4.12 Rotating equipment

4.12.1 General requirements

- a) Rotating equipment shall be designed for the pressures, temperatures and fluids to which they may be subjected under normal operating conditions.
- b) Fluid inlet and outlet lines shall be adequately protected from damage due to vibration.
- c) Shaft seals shall be compatible with the pumped fluids and the operating temperatures and pressures expected in normal and abnormal operation and during normal and emergency shutdowns.
- d) Shaft seals shall be designed such that hazardous fluid leakage is avoided. If shaft seals leak hazardous fluids, the manufacturer shall provide hazardous fluid containment or dilution means as necessary to avoid risks to health or safety.
- e) Motors, bearings, and seals shall be suitable for the expected duty cycles.

4.12.2 Compressors

4.12.2.1 Where appropriate, packaged compressors shall conform to one of the following standards: ISO 5388, ISO 10439 (all parts), ISO 10442, ISO 13707, ISO 10440-1, ISO 10440-2 or ISO 13631.

4.12.2.2 Unless considered unnecessary by the risk-analysis assessment in 4.1, compressors, or compressor systems, shall be provided with the following:

- a) Pressure-relief devices that limit each stage pressure for the compression cylinder and piping associated with that stage of compression.
This requirement is only applicable when the compression equipment is capable of generating pressure that exceeds the design pressure.
- b) An automatic shutdown control for high discharge and low suction pressure.
- c) Where required to restart the compressor after shutdown, an unloading device that captures and recycles blow-down gas for re-use, and/or safe venting.
- d) A pressure-limiting device to avoid over pressurization at the inlet.

4.12.2.3 Compressors excluded from the scope of the standards referenced in 4.12.2.1 due to small capacity or low discharge pressure need only comply with the requirements specified in 4.12.2.2.

Packaged low-discharge pressure compressors (fans and blowers) shall be guarded according to ISO 12499 (see also 4.4.4).

4.12.3 Pumps

4.12.3.1 Packaged electric pumps for process liquids shall conform to ISO 13709 or ISO 14847, if applicable.

Packaged electric pumps for water shall conform to IEC 60335-2-51, if applicable.

4.12.3.2 Electric pumps, or electric pump systems, shall be provided with the following:

- a) Pressure-relief devices that limit both inlet and outlet pressure to less than the design pressure of the piping. If the shut-off head of the electric pump is less than the pressure rating of the piping, relief valves are not required.
- b) An automatic shutdown control for high discharge pressure.

4.12.3.3 Pumps excluded from the scope of the standards referenced in 4.12.3.1 due to small capacity or low discharge pressure shall comply with the requirements specified in 4.12.3.2 and in 4.7.

4.13 ~~Cabinets~~ Enclosures

4.13.1 Fuel cell power system ~~cabinets~~ enclosures shall have sufficient strength, rigidity, durability, resistance to corrosion and other physical properties to support and protect all fuel cell power system components and piping; and, in addition, to meet the requirements of storage, transport, installation, and final location conditions.

4.13.2 Fuel cell power system ~~cabinets~~ enclosures intended for use indoors or under conditions of weather-protected outdoor locations shall be designed and tested so as to meet a minimum IP20 rating according to IEC 60529.

4.13.3 The fuel cell power system intended for use outdoors shall be designed and tested so as to meet a minimum IP23 rating.

4.13.4 Ventilation openings shall be so designed that they will not become obstructed during normal operation either by dust, snow or vegetation in accordance with the expected application.

4.13.5 All materials used to construct ~~cabinets~~ enclosures, including joints, vents, and gaskets of doors shall be capable of withstanding the physical, chemical and thermal conditions that are reasonably foreseeable throughout the fuel cell power system life.

4.13.6 Access panels, covers or insulation that need to be removed for normal servicing and accessibility shall be designed such that repeated removal and replacement will not cause damage or impair insulating value.

4.13.7 Access panels, covers or insulation that need to be removed for normal servicing and accessibility shall not be interchangeable if that interchange may lead to an unsafe condition.

4.13.8 Any access panel, cover or door that is intended to protect equipment from entry ~~by users or untrained personnel~~ shall have means for retaining it in place and shall require the use of a tool, key or similar mechanical means to open. For residential units, this shall include all access panels, covers or doors.

4.13.9 Means shall be provided to drain collected liquids and to pipe them to the exterior for disposal or redirect them to processes associated with the fuel cell power system.

4.13.10 Where personnel can fully enter the ~~cabinet~~ enclosure, access procedures shall be provided in the product's technical documentation.

4.14 Thermal insulating materials

Insulation systems employed in the fuel cell power system shall be designed to attain:

- chemical compatibility with the metals being insulated, the atmosphere and temperatures to which the systems will be exposed, and the various components of the insulation system itself;
- protection of insulation systems from expected thermal and mechanical abuse (including damage by atmospheric conditions);
- fire safety, by limiting surface temperatures of heat-producing objects to prevent the ignition of materials in proximity to them;
- future accessibility of piping, fittings, etc. for maintenance purposes.

In particular, thermal insulating materials and their internal bonding or adhesive attachment means mounted on components of the fuel cell power system shall

- be mechanically or adhesively retained in place and shall be protected against displacement or damage from anticipated loads and service operation,
- withstand all air velocities, temperatures and fluids to which they may be subjected in normal operation.

If necessary, to avoid hazards to health and safety, the manufacturer shall specify in the maintenance manual the thermal insulation system inspection and safety requirements.

4.15 Utilities

4.15.1 General requirements

The fuel cell power system shall be designed and constructed such that in the case of the loss of the utility supply the system will not cause

- a) any health, safety or environmental hazards, or
- b) permanent damage to the system.

4.15.2 Water supply

- a) Where the fuel cell power system requires water to operate, it shall be provided through a connection to an on-site water supply in accordance with local regulations, or through a self-contained water source. Alternatively, it shall be shown to produce water in sufficient quantities during operation.
- b) Process water shall be prevented from contaminating potable water sources in accordance with local regulations.
- c) If applicable, means shall be provided to prevent backflow of steam into the water treatment system of the fuel cell power system. A suitable check valve or equivalent device meets the intent of this provision.

4.15.3 Fuel gas supply

If applicable, means shall be provided to prevent backflow of processed fuel gas and/or purge gases into the fuel source.

4.15.4 Electrical connections

4.15.4.1 Service receptacle

A service receptacle outlet, or lighting circuit, not under control of a disconnecting means may be part of the fuel cell power system, provided

- a) the voltage does not exceed nominal domestic mains voltage,
- b) the receptacle is earthed,

- c) the receptacle is so located as not to constitute a hazard when servicing the fuel cell power system, and
- d) a suitable marking indicating the voltage and current limitation of the receptacle is located adjacent to the receptacle.

4.15.4.2 Disconnection from the mains supply

4.15.4.2.1 Lock-outs

Any electrical disconnection devices provided to shut power down for the safety of service personnel shall be provided with a means for physically locking-out the disconnection device to prevent inadvertent reconnection before servicing has been completed.

NOTE Instructions can be provided to allow servicing parts of the equipment with or without opening the disconnection device.

4.15.4.2.2 Disconnection devices

Disconnection devices shall be provided to disconnect the fuel cell ~~generator~~ power system from the AC or DC supplies for servicing ~~by qualified personnel~~. The means of isolation can be located either in the service access area or external to the equipment. The disconnection shall be suitable for the overvoltage category of the intended application. If a disconnection device is incorporated in the equipment, it shall be connected as closely as practicable to the incoming supply. Functional switches are permitted as disconnection devices, provided that they comply with all the requirements for such devices. For stationary fuel cell power systems, the disconnection device shall be incorporated in the equipment, unless the equipment is accompanied by installation instructions stating that an appropriate disconnection device shall be provided external to the equipment.

4.15.4.2.3 Parts which remain energized

Parts on the supply side of a disconnection device in the equipment which remain energized when the disconnection device is switched off shall be guarded and labelled so as to reduce the likelihood of accidental contact by a service person.

4.15.4.2.4 Disconnect operation

If the operating means of the disconnection device is operated vertically rather than rotationally, or horizontally, the “UP” position of the operating means shall be in the “ON” position.

4.15.4.2.5 Three-phase equipment

For three-phase equipment, the disconnection device shall disconnect simultaneously all line conductors of the AC mains supply. For equipment requiring a neutral connection to a power distribution system, the disconnection device shall be a four-pole device and shall disconnect all line conductors and the neutral conductor. If this four-pole device is not provided in the equipment, the installation instructions shall specify the need for the provision of the device external to the equipment. If a disconnection device interrupts the neutral conductor, it shall simultaneously interrupt all line conductors.

4.15.4.2.6 Single-phase and DC equipment

A disconnection device, if provided in or as part of the equipment, shall disconnect both poles simultaneously, except that

- a) if it is possible to rely on the identification of the earthed conductor in the DC mains supply, or an earthed neutral in an AC mains supply, it is permitted to use a single-pole disconnection device that disconnects the unearthed (line) conductor, or
- b) if it is not possible to rely on the identification of the earthed conductor in the DC mains supply, or an earthed neutral in an AC mains supply, and the equipment is not provided

with a two-pole disconnection device, the installation instructions shall specify that a two-pole disconnection device is to be provided external to the equipment.

4.15.4.3 Safety shutdowns – Emergency stop

Manual safety shutdowns (i.e. emergency stops), if required by the risk ~~analysis~~ assessment in 4.1, shall have clearly identifiable, clearly visible and quickly accessible controls such as buttons, in accordance with ISO 13850. If the fuel cell generator is provided with an integral single emergency stop device, or terminals for connection for a remote emergency stop device, the circuit shall prevent further power supply export in any mode of operation. If reliance is placed on additional disconnection of power supplies in the building wiring, the installation instructions shall state this. Plug-connected fuel cell generators do not require an emergency switching device if the plug can perform the same function.

4.16 Installation and maintenance

4.16.1 Installation

The manufacturer shall provide instructions for the proper installation, adjustment, operation, and maintenance of the fuel cell power systems.

Errors likely to be made when fitting or refitting certain parts which could be a source of risk shall be minimized by the design of such parts or, failing this, by information given on the parts themselves and/or the housings. The same information shall be given on moving parts and/or their housings where the direction of movement shall be known to avoid a risk. Any further information that may be necessary shall be given in the instructions.

Where a faulty connection can be the source of risk, incorrect connections shall be minimized by design or, failing this, by information given on the pipes, cables, etc. and/or connector blocks.

4.16.2 Maintenance

- a) Adjustment, lubrication and maintenance points shall be located outside zones in which a person is exposed to risk of injury or damage to health; or maintenance instructions shall be provided in the product's maintenance manual specified in 7.4.5, as necessary to avoid risks to health or safety.
- b) It shall be possible to carry out adjustment, maintenance, repair, cleaning and servicing operations while the fuel cell power system is at a standstill. When adjustment, maintenance, repair, cleaning and servicing is to be conducted while the fuel cell power system is operating, the fuel cell power system shall be designed so that those functions can be performed without the risk of injury.
- c) Automated fuel cell power system components that have to be changed frequently shall be capable of being removed and replaced without the risk of injury. Access to the components shall enable these tasks to be carried out with the necessary technical means (tools, measuring instruments, etc.) in accordance with the product's technical documentation.
- d) Where, for protection of health, safety instructions or diagrams are to be adhered to the fuel cell power system, they shall be displayed using a permanent method, resistant to, or protected from, the environmental conditions of use.

4.17 Equivalent safety

The requirements of this document are not intended to constrain innovation. When considering fuels, materials, designs or constructions not specifically dealt with in this document, these alternatives shall be evaluated as to their ability to yield levels of safety and performance equivalent to those specified in this document.

5 Type tests

5.1 General requirements

5.1.1 General

A sample, representative of production, shall be examined for compliance with this document.

Each new design shall be subjected to the type tests. Components making up the system that have been pre-certified need not be re-tested when applied within their rating and listing requirements.

In order to obtain the required operating conditions, type tests shall be performed in a test environment simulating that for which the fuel cell power system is designed. In particular, the test environment shall provide interfaces at boundary limits according to the designed application of the fuel cell power system (see Figure 1). It is recommended that the type tests be performed in the order described in 5.4 through 5.21. The type test under abnormal conditions may be destructive.

Test measurements shall be converted to the following reference conditions:

- temperature (15 °C);
- pressure (101,325 kPa).

5.1.2 Operating parameters for tests

5.1.2.1 Unless there are specific test conditions called for elsewhere in this document, test conditions shall be formulated from the most unfavourable combination of the manufacturer's operating specifications and the parameters set out below:

- a) supply voltage;
- b) supply frequency;
- c) physical location of equipment and position of movable parts;
- d) operating mode;
- e) adjustment of thermostats, regulating devices or similar controls in ~~end~~-user access areas, which are
 - 1) adjustable without the use of a tool, or
 - 2) adjustable using a means, such as a key or a tool, deliberately provided for the ~~end~~ user.

5.1.2.2 Except where otherwise stated in the particular clauses, measurements shall be carried out with the maximum uncertainties indicated below:

- | | |
|---|--|
| a) atmospheric pressure (Pa) | (± 0,5 kPa); |
| b) combustion chamber and test flue pressure (Pa) | ± 5 % of full scale or (± 50 Pa); |
| c) gas pressure (Pa) | ± 2 % of full scale; |
| d) water-side pressure loss (Pa) | ± 5 %; |
| e) water rate (l/h , m ³ /h) | ± 2 %; |
| f) gas rate (m ³ /h) | ± 2 %; |
| g) air rate (m ³ /h) | ± 2 %; |
| h) time (h) | |
| – for ignition timings | ± 0,2 s; |
| – for all other timings | ± 0,1 %; |

- i) ~~auxiliary~~ electrical energy/~~performance~~ (kWh ~~or kW~~) $\pm 2 \%$;
- j) temperatures: ($^{\circ}\text{C}$ or K)
 - ambient $\pm 1 \text{ K}$;
 - water $\pm 2 \text{ K}$;
 - combustion products $\pm 5 \text{ K}$;
 - fuel gas $\pm 1 \text{ K}$ at $T < 100 \text{ }^{\circ}\text{C}$;
 - $\pm 1 \%$ of reading in $^{\circ}\text{C}$: $100 \text{ }^{\circ}\text{C} \leq T < 300 \text{ }^{\circ}\text{C}$;
 - $\pm 5 \%$ of reading in $^{\circ}\text{C}$: $T \geq 300 \text{ }^{\circ}\text{C}$;
 - surface $\pm 5 \text{ K}$;
- k) CO , CO_2 and O_2 for the calculation of flue losses $\pm 6 \%$ of reading;
- l) gas calorific value (kWh/m^3) $\pm 1 \%$;
- m) gas density (kg/m^3) $\pm 1 \%$;
- n) mass (kg) $\pm 1 \%$;
- o) torque ($\text{N}\cdot\text{m}$) $\pm 10 \%$;
- p) force (N) $\pm 10 \%$;
- q) current (A) $\pm 1 \%$;
- r) voltage (V) $\pm 1 \%$;
- s) electrical power (W, kW) $\pm 2 \%$.

The full range of the measuring apparatus is chosen to be suitable for maximum anticipated value.

For the determination of the leakage rate, a method is used which gives such accuracy that the error in its determination does not exceed 2 % of related volume per hour.

The measurement uncertainties indicated concern individual measurements. For measurements requiring a combination of individual measurements (for example, efficiency measurements), the lower uncertainties associated with individual measurements may be necessary to limit the total uncertainty.

5.1.2.3 Normal operating voltages are determined by the manufacturer's specifications.

5.2 Test fuels

5.2.1 A fuel cell power system intended for use with natural gas shall have the tests specified in a) through f) below conducted with a gas whose composition and supply pressures reflect those of commercially available natural gas at the maximum and minimum expected gas pressure. If required by the country of destination, the following tests shall also be conducted with limit gases:

- a) burner operating characteristics (5.9);
- b) effective ignition (5.10.2.2);
- c) ignition – voltage variation (5.10.2.3);
- d) recycling or spark restoration (5.10.2.6);
- e) pilot flame reduction (5.10.2.7);
- f) delayed ignition (5.10.2.8).

5.2.2 A fuel cell power system intended for use with liquefied petroleum gases shall have the tests specified in a) through f) below conducted with a gas whose composition and supply pressures reflect those of commercially available liquefied petroleum gas at the maximum and

minimum expected gas pressure. If required by the country of destination, the following tests shall also be conducted with limit gas n-butane:

- a) burner operating characteristics (5.9);
- b) effective ignition (5.10.2.2);
- c) ignition – voltage variation (5.10.2.3);
- d) recycling or spark restoration (5.10.2.6);
- e) pilot flame reduction (5.10.2.7);
- f) delayed ignition (5.10.2.8).

5.2.3 A fuel cell power system intended for use with other types of fuel(s) (see Clause 1) shall be tested with test fuel(s) of composition and supply characteristics representative of the fuel(s). If the fuel has a range of composition, the following tests shall be conducted at the extremes of the composition range:

- a) burner operating characteristics (5.9);
- b) effective ignition (5.10.2.2);
- c) ignition – voltage variation (5.10.2.3);
- d) recycling or spark restoration (5.10.2.6);
- e) pilot flame reduction (5.10.2.7);
- f) delayed ignition (5.10.2.8).

5.3 Basic test arrangements

When the tests are conducted, the entire fuel cell power system, including any air filters, start-up devices, venting or exhaust systems and all field furnished equipment shall be installed and operated in accordance with the manufacturer's instructions.

Unless otherwise stated, the fuel cell power system shall be operated:

- a) with the inlet supply pressure as defined in 5.2;
- b) within ± 5 % of the rated voltage and frequency, and within ± 10 % of the rated power output as specified by the manufacturer;
- c) within ± 5 % of the rated fuel consumption when operated at rated conditions;
- d) at ambient temperature and pressure which do not degrade the results of the tests.

Testing shall commence when the fuel cell power system components are at equilibrium temperature, unless otherwise specified.

5.4 Leakage tests

5.4.1 General

The procedures in 5.4 shall be performed twice: prior to and following the conduction of all non-destructive tests specified in 5.6 through to 5.21.

5.4.2 Pneumatic leakage tests

5.4.2.1 General

Portions of the fuel cell power system subject to this test shall not leak externally in excess of the limit specified below when tested with appropriate gases or vapours (for example, the nominal operating gases, clean dry air or inert gas as specified by the manufacturer) that correlate with the expected constituents during operation and shutdown.

For the following items only the pass/fail criterion given in Table 2 as “no bubble” applies to supply gas circuit.

Prior to conducting this test, it shall be established which components are subject to the same internal pressure during normal operation of the fuel cell power system. These components shall comprise an individual test section which shall then be pressurized separately and, when deemed necessary, isolated from the rest of the fuel cell power system by any convenient means.

A suitable pressurizing system, capable of supplying the gaseous medium at the required test pressure, and a suitable flow-measuring device, capable of measuring the leakage rate with an accuracy of 2 %, shall be connected to the inlet of a test section. The flow measuring device shall be located between the pressuring system and the test section to be pressurized. The outlet of the test section shall be sealed by any convenient means. All functional parts shall be caused to assume their open position so that the required test pressure is exerted on all parts of the test section. Alternatively, another leak detection means such as a pressure decaying device may be used.

The gaseous medium shall be gradually admitted to the test section so that a uniform gauge pressure of not less than the pressure stipulated in Table 2 is attained gradually ~~in approximately 1 min until stabilized~~. This pressure shall be maintained for at least ~~± 10 min, or greater as appropriate~~, at which time any leakage, as indicated by the flow-measuring device, shall be noted.

5.4.2.2 Test method 1

If natural ventilation is used to compensate for fuel leakage, the allowable leakage shall be determined by means of a gas detector to ensure that the area concentration does not exceed 25 % of the lower flammability limit (LFL) in an unclassified zone as defined by 4.6.

5.4.2.3 Test method 2

If mechanical ventilation is used to compensate for fuel leakage, the allowable leakage rate is determined by the formula:

$$L = 0,01 \times (V/R)$$

where

L is the allowable leakage rate, in cubic metres per hour, for each part or all parts respectively;

$R = (TGSG / FGSG)^{1/2}$, where $TGSG$ is the test gas specific gravity and $FGSG$ is the fuel gas specific gravity;

or

$R = (\mu_{\text{test}}/\mu_{\text{fuel}})$ where μ_{test} is the test gas absolute viscosity and μ_{fuel} is the fuel gas absolute viscosity;

The R value that results in the lower allowable leakage rate shall be reported.

V is the minimum ventilation rate, in cubic metres per hour of air.

A correction factor may be used when fuel gas of less than 100 % flammables is used:

$$L = 0,01 \times (V/R) \times (1/C)$$

where C is the concentration of combustibles.

5.4.2.4 Test method 3

In the case of odorized natural gas and/or liquefied petroleum circuits meeting 4.6.1 g) 2) and for the supply gas circuit, it shall be demonstrated that there is no leakage after having removed and replaced all routinely serviced assemblies five times. This can be verified by use of an industry accepted leakage detection fluid applied at all associated joints and fittings. There shall be no bubbles present under the test parameters of Table 2.

Table 2 – Leakage test requirements a, d, e

Hazard	Test type	System design conditions	Test parameters	Pass/fail criteria
Flammable	Hydrostatic ^b	All pressures	1,5 times design pressure	No leakage as defined in 5.4.3
	Pneumatic ^c	All pressures	1,1 times design pressure	No bubbles using an industry accepted leakage detection fluid
				5.4.2.2 Test method 1
				5.4.2.3 Test method 2
Toxic (e.g. carbon monoxide)	Hydrostatic ^b	≥ 100 kPa (gauge)	1,5 times design pressure	No leakage as defined in 5.4.3
		< 100 kPa (gauge)	1,0 1,1 times design pressure	No leakage as defined in 5.4.3
	Pneumatic ^c	All pressures	1,1 times design pressure	No bubbles using an industry accepted leakage detection fluid
				5.4.2.2 Test method 1
				5.4.2.3 Test method 2
				Acceptable leakage as defined in 5.20
Thermal-burn hazard	Gas (e.g. air and exhaust)	≥ 300 °C	During fuel cell power system operation	Ambient temperature adjacent to the piping system and/or the piping insulation cannot exceed 300 °C. Can be conducted concurrently with test in 5.12.
		< 300 °C	No requirement	No requirement
	Liquid (e.g. coolants)	≥ 1,1 MPa or ≥ 120 °C	1,5 times design pressure for hydrostatic	No leakage as defined in 5.4.3
			1,1 times design pressure for pneumatic	No bubbles using an industry accepted leakage detection fluid
		< 1,1 MPa and < 120 °C	1,0 times design pressure for hydrostatic	No leakage as defined in 5.4.3
			1,0 times design pressure for pneumatic	No bubbles using an industry accepted leakage detection fluid

^a The test pressure at any point in the piping system shall not exceed the maximum allowable test pressure of any non-isolated components, such as vessels, pumps, or valves. The pressure shall be continuously maintained for a minimum of 10 min ~~and may then be reduced to the design pressure and held for such time as may be necessary to conduct the examinations for leakage.~~

^b Pneumatic testing may alternately be used assuming component compatibility and the concurrence of the certifying body.

^c Hydrostatic testing may alternately be used assuming component compatibility and the concurrence of the certifying body.

^d The design pressure is the highest pressure that may occur under any and all operating modes, including steady state and transient.

^e If a system is tested in sections, the summation of the leakage of all sections shall not exceed the leakage requirements of this table.

5.4.3 Hydrostatic leakage tests

Portions of the fuel cell power system subject to this test shall not leak externally.

The test fluid shall be the design liquid. If the manufacturer considers that testing with the design liquid is impractical, then the test liquid shall be water. If there is the possibility of damage due to freezing or to adverse effects of water on the piping system, another suitable non-toxic liquid may be used. If the liquid is flammable, its flash point shall be at least 50 °C and consideration shall be given to the test environment.

The hydrostatic test pressure shall not be less than the pressure stipulated in Table 2.

All external surfaces of the components that convey liquids shall be made visible to check for leakage. If certain components cannot be made visible, provisions shall be made to capture and route leakage to a point of visibility. If leak routing cannot be achieved then an alternate leak check will need to be devised by the manufacturer.

Prior to test performance, it shall be determined which liquid-conveying components are subject to the same internal pressure during normal operation of the fuel cell power system. These components shall comprise an individual test section, which shall then be pressurized separately and, when deemed necessary, isolated from the rest of the power system by any convenient means.

The test apparatus shall be filled with the liquid medium and connected to a suitable hydraulic system, including a pressure-measuring device capable of sustaining the required test pressure. Care should be taken to vent air from the test section during liquid fill.

The test pressure shall be gradually increased so that a uniform gauge pressure is attained. This pressure shall be maintained for at least 10 min, or longer as necessary, to complete the leak checks, while inspecting all external surfaces of the system for any sign of leakage. If a leak routing system is employed, the test pressure shall be held for a minimum of 3 h.

No liquid leakage is allowed. Any visible evidence of leakage is a cause for failing the test.

5.5 Strength tests

5.5.1 General

Any certified component(s), with a pressure rating of not less than the system's design pressure shall be considered as complying with the applicable provision(s) of 5.5.

5.5.2 Pneumatic strength tests

Portions of the fuel cell power system subject to this test shall not rupture, fracture, deform or exhibit other signs of physical damage when tested with appropriate gases or vapours (for example, the nominal operating gases, clean dry air or inert gas as specified by the manufacturer) that correlate with the expected constituents during operation and shutdown.

Prior to conducting this test, it shall be established which components are subject to the same internal pressure during normal operation of the fuel cell power system. These components shall comprise an individual test section which shall then be pressurized separately and, when deemed necessary, isolated from the rest of the fuel cell power system by any convenient means.

A suitable pressurizing system, capable of supplying the gaseous medium at the required test pressure shall be connected to the inlet of a test section. All functional components shall be