

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Fuel cell technologies –
Part 2: Fuel cell modules**

**Technologies des piles à combustible –
Partie 2: Modules à piles à combustible**

Withdrawn



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FUEL CELL TECHNOLOGIES –**Part 2: Fuel cell modules****FOREWORD**

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International Standard IEC 62282-2 has been prepared by IEC technical committee 105: Fuel cell technologies.

This second edition cancels and replaces the first edition, published in 2004, its amendment 1 (2007) and constitutes a technical revision.

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

- inclusion of definitions for hazards and hazardous locations based on the IEC 60079 series;
- the general safety strategy is modified to reflect the needs for different application standards. The modifications are in line with similar modifications made to IEC 62282-3-100;
- the electrical components clause is modified to reflect the needs for different application standards. The modifications are in line with similar modifications made to IEC 62282-3-100;

- the marking and instructions have been enlarged to provide the system integrator with the necessary information.

The text of this standard is based on the following documents:

FDIS	Report on voting
105/378/FDIS	105/389/RVD

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

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

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

The reader's attention is drawn to the fact that Annex B lists all of the “in-some-country” clauses on differing practices of a less permanent nature relating to the subject of this standard.

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

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- withdrawn,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

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INTRODUCTION

Fuel cell modules are electrochemical devices which convert continuously supplied fuel, such as hydrogen or hydrogen rich gases, alcohols, hydrocarbons and oxidants to d.c. power, heat, water and other by-products.

Fuel cell modules are sub-assemblies that are integrated into end-use products incorporating one or more fuel cell stacks and, if applicable, additional components.

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FUEL CELL TECHNOLOGIES –

Part 2: Fuel cell modules

1 Scope

This part of IEC 62282 provides the minimum requirements for safety and performance of fuel cell modules and applies to fuel cell modules with the following electrolyte chemistry:

- alkaline;
- polymer electrolyte (including direct methanol fuel cells)¹;
- phosphoric acid;
- molten carbonate;
- solid oxide;
- aqueous solution of salts.

Fuel cell modules can be provided with or without an enclosure and can be operated at significant pressurization levels or close to ambient pressure.

This standard deals with conditions that can yield hazards to persons and cause damage outside the fuel cell modules. Protection against damage inside the fuel cell modules is not addressed in this standard, provided it does not lead to hazards outside the module.

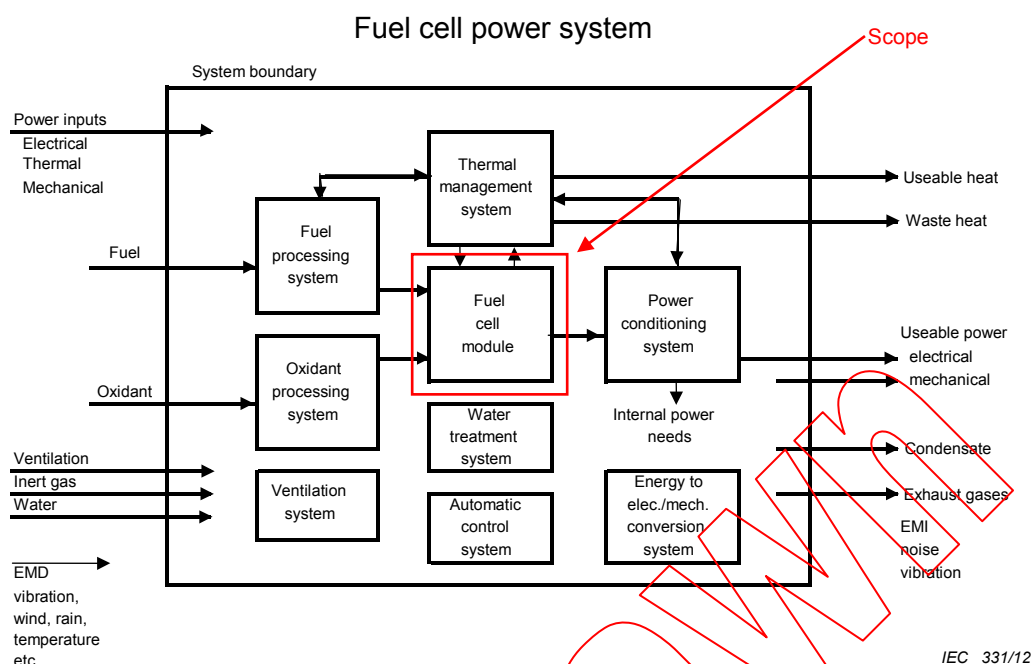
These requirements may be superseded by other standards for equipment containing fuel cell modules as required for particular applications.

This standard does not cover road vehicle applications.

This standard is not intended to limit or inhibit technological advancement. An appliance employing materials or having forms of construction differing from those detailed in the requirements of this standard may be examined and tested according to the purpose of these requirements and, if found to be substantially equivalent, may be considered to comply with this standard.

The fuel cell modules are components of final products. These products require evaluation to appropriate end-product safety requirements.

¹ Also known as proton exchange membrane fuel cell.



Key

EMD electromagnetic disturbance
EMI electromagnetic interference

Figure 1 – Fuel cell system components

This standard covers only up to the d.c. output of the fuel cell module.

This standard does not apply to peripheral devices as illustrated in Figure 1.

This standard does not cover the storage and delivery of fuel and oxidant to the fuel cell module.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60079 (all parts), *Explosive atmospheres*

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

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

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

IEC 60352 (all parts), *Solderless connections*

IEC 60512-15 (all parts), *Connectors for electronic equipment – Tests and measurements – Part 15: Connector tests (mechanical)*

IEC 60512-16 (all parts) *Connectors for electronic equipment – Tests and measurements – Part 16: Mechanical tests on contacts and terminations*

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

IEC 60617, *Graphical symbols for diagrams*

IEC 60695 (all parts), *Fire hazard testing*

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

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

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

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*

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

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

EN 50178, *Electronic equipment for use in power installations*

3 Terms and definitions

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

3.1

acceptance test

contractual test to prove to the customer that the item meets certain conditions of its specification

[SOURCE: IEC 60050-151:2001, 151-16-23] [1]²

3.2

allowable differential working pressure

maximum pressure difference between the anode and cathode side specified by the manufacturer which the fuel cell module can withstand without any damage or permanent loss of functional properties

² References in square brackets refer to the bibliography.

3.3

allowable working pressure

maximum gauge pressure specified by the manufacturer which the fuel cell module can withstand without any damage or permanent loss of functional properties

Note 1 to entry: For fuel cell modules incorporating pressure relief devices, this is normally used to define the threshold of the set pressure.

3.4

ambient temperature

temperature of the medium surrounding a device, equipment or installation which may affect the performance of the device, equipment or installation

3.5

conditioning

(related to cells/stacks) preliminary step that is required to properly operate a fuel cell module (3.8) and that is realized following a protocol specified by the manufacturer

Note 1 to entry: The conditioning may include reversible and/or irreversible processes depending on the cell technology.

3.6

fuel cell

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

Note 1 to entry: The fuel and oxidant are typically stored outside the fuel cell and transferred into the fuel cell as they are consumed.

3.7

fuel cell stack

assembly of cells, separators, cooling plates, manifolds and a supporting structure that electrochemically converts, typically, hydrogen rich gas and air reactants to DC power, heat and other reaction products

[SOURCE: IEC 62282-1:2010, 3.50] [2]

3.8

fuel cell module

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

Note 1 to entry: A fuel cell module is comprised of the following main components: one or more fuel cell stack(s), piping system for conveying fuels, oxidants and exhausts, electrical connections for the power delivered by the stack(s) and means for monitoring and/or control. Additionally, a fuel cell module may comprise: means for conveying additional fluids (e.g. cooling media, inert gas), means for detecting normal and/or abnormal operating conditions, enclosures or pressure vessels and module ventilation systems.

3.9

rated current

maximum continuous electric current as specified by the fuel cell module manufacturer at which the fuel cell module has been designed to operate

3.10

crossover

cross leakage

leakage between the fuel side and the oxidant side, of a fuel cell, in either direction, generally through the electrolyte

3.11

gas leakage

sum of all gases leaving the fuel cell module except the intended exhaust gases

Note 1 to entry: Gas leakage may occur from

- the fuel cell stack;
- associated pressure relief devices;
- other gas ducting and flow controlling components.

3.12

hazard

potential source of harm in the form of physical injury to the health of people, property or the environment

3.13

hazardous area

classified area

area or space where combustible dust, ignitable fibres, or flammable, volatile liquids, gases, vapours or mixtures are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures

3.14

heat deflection temperature

temperature at which a standard test bar deflects a specified distance under load

Note 1 to entry: It is used to determine short-term heat resistance.

3.15

lower flammability limit

LFL

minimum concentration of fuel in a fuel-air mixture where a combustion can be ignited by an ignition source

Note 1 to entry: A fuel-air mixture is flammable when combustion can be started by an ignition source. The main component is the proportions or composition of the fuel-air mixture. A mixture that has less than a critical amount of fuel, known as the lower flammability limit (LFL) or more than a critical amount of fuel, known as the rich or upper flammability limit (UFL), will not be flammable.

3.16

maximum operating pressure

maximum pressure, specified by the manufacturer of a component or system, at which it is designed to operate continuously

Note 1 to entry: The maximum operating pressure is expressed in Pa.

Note 2 to entry: Includes all normal operation, both steady state and transient.

3.17

minimum voltage

lowest voltage that a fuel cell module is able to produce continuously at its rated power or during its maximum permissible overload conditions, whichever voltage is lower

Note 1 to entry: The minimum voltage is expressed in V.

3.18

natural ventilation

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

3.19

open-circuit voltage

voltage across the terminals of a fuel cell with fuel and oxidant present and in the absence of external current flow

Note 1 to entry: The open-circuit voltage is expressed in V.

3.20

routine test

conformity test made on each individual item during or after manufacture

[SOURCE: IEC 60050-151:2001, 151-16-17]

Note 1 to entry: Not to be confused with “Conformity test” [IEC 60050-151:2001, 151-16-15]: test for conformity evaluation or “Conformity evaluation” [IEC 60050-151:2001, 151-16-14]: systematic examination of the extent to which a product, process or service fulfils specified requirements.

3.21

standard conditions

test or operating conditions that have been predetermined to be the basis of the test in order to have reproducible, comparable sets of test data

3.22

safeguarding

control system actions, based on process parameters, taken to avoid conditions that might be hazardous to personnel or might result in damage to the fuel cell or its surroundings

3.23

safety extra low voltage

SELV

voltage under normal and single fault conditions that do not exceed 30 V r.m.s. or 42,4 V peak/d.c. in dry environments or when wet contact is likely to occur, 15 V r.m.s. or 21,2 V peak/d.c.

3.24

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 two readings 15 min apart

3.25

thermal stability

stable temperature isothermal conditions

3.26

type test

conformity test made on one or more items representative of the production

[SOURCE: IEC 60050-151:2001, 151-16-16]

Note 1 to entry: Not be confused with “Conformity test” [IEC 60050-151:2001, 151-16-15]: test for conformity evaluation or “Conformity evaluation” [IEC 60050-151:2001, 151-16-14]: systematic examination of the extent to which a product, process or service fulfils specified requirements.

4 Requirements

4.1 General safety strategy

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

- a) all reasonably foreseeable hazards, hazardous situations and events throughout the anticipated fuel cell power system's lifetime have been identified (see Annex A for a listing of typical hazards),
- b) the risk for each of these hazards has been estimated from the combination of probability of occurrence of the hazard and of its foreseeable severity,

- c) the two factors which determine each one of the estimated risks (probability and severity) have been eliminated or reduced to a level not exceeding the acceptable risk level, as far as is practically possible, through
- 1) inherently safe design of the construction and its methods, or
 - 2) passive control of energy releases without endangering the surrounding environment (for example, burst disks, release valves, thermal cut-off devices) or by safety related control functions, and
 - 3) for residual risks which could not have been reduced by the measures according to 1) and 2), provision of labels, warnings or requirements of special training shall be given, considering that such measures need to be understood by the persons which 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 e.g.:

- IEC 62061 (respectively ISO 13849-1) for applications according to IEC 60204-1;
- IEC 60730-1 for appliances according to IEC 60335-1;
- IEC 61508 (all parts) 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 [3];
- SAE J1739 [4];
- IEC 61025 [5].

The assessment shall also cover the following possible risks:

- stack temperature, and
- stack and/or cell voltage,
- pressure of pressurized parts.

Furthermore, care shall be taken to address the following:

- mechanical hazards – sharp surfaces, tripping hazards, moving masses and instability, strength of materials, and liquids or gases under pressure;
- electrical hazards – contact of persons with live parts, short-circuits, high voltage;
- EMC hazards – malfunctions of the fuel cell module when exposed to electromagnetic phenomena or malfunctions of other (nearby) equipment due to electromagnetic emissions from the fuel cell module;
- thermal hazards – hot surfaces, release of high temperature liquids or gases, thermal fatigue;
- fire and explosion hazards – flammable gases or liquids, potential for explosive mixtures during normal or abnormal operating conditions, potential for explosive mixtures during faulted conditions;
- malfunction hazards – unsafe operation due to failures of software, control circuit or protective/safety components or incorrect manufacturing or misoperation;
- material and substance hazards – material deterioration, corrosion, embrittlement, toxic releases;
- waste disposal hazards – disposal of toxic materials, recycling, disposal of flammable liquids or gases;
- environmental hazards – unsafe operation in hot/cold environments, rain, flooding, wind, earthquake, external fire, smoke.

4.2 Design requirements

4.2.1 General

The fuel cell module shall be designed in accordance with a risk assessment performed by the fuel cell module manufacturer. All parts shall be

- a) suitable for the range of temperatures, pressures, flow rates, voltages and currents to which they are subjected during intended usage, and
- b) resistant to the reactions, processes and other conditions to which they are exposed during intended usage.
- c) The quality and thickness of the materials used in the fuel cell module, their fitting elements and terminals and the method of assembling the various parts, shall be such that the constructional and operational characteristics are not significantly altered during a reasonable lifetime and under normal conditions of installation and use. All parts of the fuel cell module shall withstand the mechanical, chemical and thermal conditions to which they may be subjected when the end user product is used normally.

Fuel cell module enclosures shall comply with the requirements given by IEC 60529 to fit into the application system. The fuel cell module shall carry the IP-Code accordingly.

NOTE An IP00 rating indicating non-protected may be appropriate when the end use equipment has a protective enclosure.

4.2.2 Behaviour at normal and abnormal operating conditions

The fuel cell module shall be designed in such a way that it withstands all normal operating conditions as defined by the manufacturer's specification without any damage. Abnormal operating conditions shall be covered according to 4.1.

4.2.3 Leakage

Depending on the design, leakage of combustible gases or liquids may occur (test see 5.3). The gas leakage rate shall be included in the specification document, so that the integrator of the fuel cell system can determine the minimum capacity of the required ventilation system (see 7.4.1, r), purging and ventilation flow rate requirements.

The fault mode "crossover" shall be part of the risk assessment according to 4.1. Measures e. g. "cell voltage monitors" shall be designed according to the relevant standard given in 4.1.

When crossover protection is not included in the fuel cell module, the product documentation shall describe any protective devices or operating procedures that have to be provided by the system integrator.

NOTE For classification of hazardous areas, consider IEC 60079-10.

4.2.4 Pressurized operation

If fuel cell modules include gas-tight and pressurized enclosures, those enclosures shall comply with national regulations.

Pressure operation conditions that could generate hazardous conditions outside of the module shall be identified (see 4.1) and the information conveyed to the system integrator

NOTE The following modules present particular properties:

PEFC modules

Pressure is not a significant design factor for the design of a PEFC (polymer electrolyte fuel cell stack). The dimensioning, choice of material and manufacturing rules of a PEFC stack are based primarily on requirements for sufficient strength, rigidity and stability to meet the static, dynamic, and/or other operational characteristics. For example, a design using coaxial force compression hardware leaks before it breaks.

PAFC modules

The PAFC (phosphoric acid fuel cell) module usually operates under atmospheric pressure.

MCFC modules

For a pressurized operation of a MCFC (molten carbonate fuel cell), the MCFC module is integrated into an MCFC system. This MCFC system provides the housing of the MCFC module and is designed according to the applicable national and international codes and standards for pressurized systems.

A hazard due to pressure associated with an MCFC module can be excluded due to the housing, which is in accordance with the regulations mentioned.

SOFC modules

If pressurized operation of a SOFC (solid oxide fuel cell) is foreseen, the SOFC module is integrated into the SOFC power system. For that application, the SOFC module is enclosed within a pressure vessel designed, manufactured and equipped according to applicable national and international codes and standards for pressurized systems.

4.2.5 Fire and ignition**4.2.5.1 General**

The fuel cell module shall be protected by means (for example, ventilation, gas detectors, controlled oxidation, operating temperatures higher than the auto-ignition temperature, etc.) such that leaking gases from, or inside, the fuel cell module cannot form explosive concentrations.

The design criteria for such means (for example required ventilation rate) shall be provided by the fuel cell module manufacturer. The means shall be provided either by the fuel cell module manufacturer or by the fuel cell system manufacturer. If the fuel cell manufacturer does not provide such means, then he shall provide the design and test criteria for such means (for example required ventilation rate).

Components and materials inside the classified gas flammable atmospheres shall be constructed or shall make use of such materials that propagation of fire and ignition is mitigated. The material flammability shall be such that a sustained fire will not be supported after electrical power and the fuel and oxidant supply have been terminated. This may be demonstrated through the selection of materials meeting V 0, V 1 or V 2 in accordance with the IEC 60695 series.

NOTE The auto-ignition temperatures commonly listed in standards such as IEC 60079-20-1[6] are the minimum temperatures at which a flammable gas mixture may ignite. The actual auto-ignition temperatures can be well above these values depending on the surface geometry, material and the actual gas mixtures. This requirement refers to an auto-ignition temperature that will ignite a flammable gas under all conditions for the chosen materials and geometry.

The requirements of the application standard as given in 4.1 shall be considered concerning "Resistance to heat and fire".

4.2.5.2 Exemptions

Membranes, or other materials within the fuel cell stack volume which comprise less than 10 % of the total fuel cell module mass, are considered to be of limited quantity and are permissible without flame spread ratings. If such material is used, this should be part of the product specification so that the system integrator can take care on it.

If the actual temperature in any location of the fuel cell module, where a flammable mixture may occur, is higher than the auto-ignition temperature, leakage of fuel gas into the oxidant or vice versa results in immediate oxidation of the flammable gas. Thus, it is obvious that no major concentrations of explosive gases can accumulate.

Whenever this temperature of such high-temperature fuel cells is lower than the auto-ignition temperature, the fuel cell module shall be transferred into a safe state (for example, by purging).

4.2.6 Safeguarding

The failure of a component within a safety control system (see 4.1 c) shall cause the fuel cell module to initiate a controlled shut-down. To ensure the required level of safeguarding (SIL-Level, performance level or class of control function) the safety relevant design shall comply with the relevant standards given in 4.1.

NOTE The controlled shut-down may include a time delay, or allow for the completion of an operational cycle, when immediate shut-down would result in a higher risk. An example may be the failure of a gas detector in a fuel cell module used as an emergency power supply.

4.2.7 Piping and fittings

4.2.7.1 General

Threaded connections of combustible gases conveying piping and fittings shall comply with ISO 23550. All other joints shall be welded, or at least have fitting connections with a defined sealing area as specified by the manufacturer. Unions, when used in fuel gas or oxygen lines, shall be of the ground-joint type or the flanged-joint type or the compression-joint type having packing resistant to the action of fuel gases.

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.

Flexible piping and associated fittings, when used for conveying gas, shall be suitable for the application. Special consideration shall be given to hydrogen pipes, such as aging behaviour, embrittlement, porosity, etc.

NOTE Information on compliance with various requirements can be found in the following standards: ISO 37, ISO 188, ISO 1307, ISO 1402, ISO 1436 and ISO 4672 [7] to [12].

4.2.7.2 Non-metallic piping systems

Polymeric and elastomeric piping, tubing and components shall be permitted under the following conditions.

Materials shall be demonstrated to be suitable over lifetime for the combined maximum operating temperatures and pressures and compatible with other materials and chemicals they will come in contact within service and during maintenance. Adequate mechanical strength shall be demonstrated according to 5.4 and 5.5.

Plastic or elastomeric components shall be protected from mechanical damage within the fuel cell module. Shielding may be used as appropriate to protect components against failure of rotating equipment or other mechanical devices housed within the unit.

Any compartment enclosing plastic or elastomeric components used to convey flammable gases shall be protected against the possibility of overheating.

If danger of fuel flow temperature more than 10 K below the lowest heat deflection temperature cannot be excluded a control system complying with the requirements according the relevant standard as given in 4.1 to cover the allocated risk shall be provided to terminate the fuel flow.

Plastic or elastomeric materials used in a hazardous location shall be electrically conductive or otherwise designed to avoid static charge build-up, e. g. by limitation of flow rate or other. Plastic or elastomeric materials with insufficient electrical conductivity shall only be used in non-hazardous areas.

4.2.7.3 Metallic piping systems

Metallic piping systems shall be suitable for the combined maximum operating temperatures and pressures and shall be compatible with other materials and chemicals they will come in contact within service and during maintenance. Metallic piping systems shall be of sufficient mechanical integrity. Adequate mechanical strength shall be demonstrated according to 5.5 and 5.6.

Metallic piping systems shall be compliant with the leakage requirement according to 5.3.

Formed piping bends shall not promote failure caused by the forming process and shall comply with the following:

- bends shall be made only with bending equipment and procedures intended for that purpose;
- all bends shall be smooth and free from buckling, cracks, or other evidence of mechanical damage;
- the longitudinal weld of the pipe shall be near the neutral axis of the bend;
- the inside radius of a bend shall be not less than the minimum radius specified by the pipe manufacturer.

4.2.8 Electrical components

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 relevant electrical product application standard(s). For example:

- IEC 60335-1 (e.g. residential/commercial and light industrial);
- IEC 60204-1 (e.g. large industrial);
- IEC 60950-1 (e.g. telecom);
- IEC 62040-1 (e.g. UPS).

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:

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

The suitability of the electrical components for the ambient conditions specified for the operation of the fuel cell system shall be communicated to the fuel cell system integrator (see 7.4.1, i): range of ambient temperature and humidity for operation and storage.

If the electric components are provided by the system integrator, he shall be informed about the necessary technical specification so that safety can be ensured.

Where an enclosed fuel cell module, operating below the auto-ignition temperature of the combustible gas, does not comply with the flammable concentration limits described in 5.12, the electrical components located within the enclosure shall be suitable for the area classification as defined in IEC 60079-10, using a protection technique defined within the IEC 60079 series.

4.2.9 Terminals and electrical connections

Power connections to external circuitry shall be

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

- b) constructed in such a way that the conductors cannot slip out from their intended location,
- c) such that proper contact is assured without damage to the conductors that would impair the ability of the conductors to fulfil their function, and
- d) so secured against turning, twisting or permanently deforming during normal tightening onto the conductor.

Connections made directly to the fuel cell shall not be appreciably impaired by conditions occurring in normal service. Terminals of the fuel cell module shall comply with IEC 60352, IEC 60512-15 (all parts) and IEC 60512-16 (all parts) or with the requirements as given for terminals and electrical connections in the application standards according to 4.2.8.

4.2.10 Live parts

The manufacturer's technical documentation shall specify according to the relevant application standards as given in 4.2.8:

- a) accessible live parts that do not meet the requirements for safety extra low voltage (SELV);
- b) accessible live parts that present a high current hazard due to shorting.

The fuel cell system integrator shall be responsible for the protection of these live parts against electric shock.

4.2.11 Insulating materials, dielectric strength

The design of all dielectrics of the fuel cell module, applied between live parts and non current-carrying metal parts, shall be in accordance with applicable standards as given in 4.2.8 for electrical equipment of appropriate voltage class.

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

Verification shall be based on the properties and characteristics of the material as defined by the manufacturer of the material.

4.2.12 Bonding

The following applies unless the relevant application standards as given in 4.2.8 are specifying it differently

Accessible not current-carrying metal parts that are likely to become energized through electrical fault, and that can lead to an electric shock, or an electrical energy hazard, shall be bonded to a common point.

To ensure good electrical contact, these connections shall be protected against corrosion. They shall also be designed so that the conductors are secured against loosening and twisting and that contact pressure is maintained.

There shall be no electrochemical corrosion between metallic parts, which form a bonding under the expected conditions of use, storage and transportation. Resistance against electrochemical corrosion may be achieved through appropriate plating or coating processes.

4.2.13 Shock and vibration

The shock and vibration limits that the fuel cell module is designed to withstand shall be included in the manufacturer's documentation.

5 Type tests

5.1 General

Type tests shall be performed in a test facility simulating the anticipated fuel cell system or the fuel cell system itself, in order to obtain the required operating conditions. In particular, the test facility for performing the type tests of normal operation can be the conditioning facility used for the initial start-up of the fuel cell module. It is recommended that the type tests be performed in the order described below. The test of abnormal conditions may be destructive.

5.2 Shock and vibration test

The fuel cell module shall be subject to the shock and vibration test limits stated in the manufacturer's documentation.

NOTE It may be that the manufacturer has not specified shock and vibration limits, in which case no tests are required.

Compliance is given if the device under test withstands the manufacturer's specified vibration and shock criteria with no evidence of damage. The device under test operates as intended after the conditioning.

5.3 Gas leakage test

This test is not applicable for fuel cell modules with

- operating temperatures higher than the auto-ignition temperature of the combustible gas (see 4.2.5), or
- fuel cells within a gas-tight vessel already proven according to the relevant national regulations.

Where it is impractical to use the full stack, a stack with a reduced, but still representative, number of cells can be used. Leakage shall be calculated based on the ratio of cell numbers.

The fuel cell module shall be operated until it attains thermal equilibrium conditions at the maximum operating temperature under full load current.

Once these conditions have been achieved, operation is ceased, the fuel cell module may be purged and the gas outlets closed; the fuel cell module temperature shall be reduced to the lowest specified operating temperature or below. The fuel cell module shall then be pressurized, either with the nominal anode gas or helium, gradually to the maximum operating pressure, defined by manufacturer, and held steady for 1 min.

The inlet pressure shall remain stable and unchanged during the time the leakage is measured. The gas leakage rate shall be measured using a flow meter located at the inlet of the fuel cell module, upstream of a pressure relief device and capable of measuring the leakage rate with an accuracy of 2 %. If helium is used as test gas, the gas leakage rate shall be corrected according to

$$R = \text{fuel gas leakage rate/test gas leakage rate} \quad (1)$$

where

$$R = (TGSG/FGSG)^{1/2} \quad (2)$$

and

TGSG is the test gas specific gravity;

FGSG is the fuel gas specific gravity;

or

$$R = \mu_{\text{test}}/\mu_{\text{fuel}}$$

where

μ_{test} is the test gas absolute viscosity;

μ_{fuel} is the fuel gas absolute viscosity.

These two formulas shall be used to calculate R and the worst-case scenario, i.e. the higher value, shall be reported.

The rate of gas leakage, including the flow rate of gas through the pressure relief valve, shall be recorded.

If the pressure relief device is not included in the test, because of, for example, hysteresis or pressure setting, then the total leakage shall be the sum of the leakage of the pressure relief device alone at maximum fuel supply pressure and that obtained from this test.

The gas leakage rate, corrected to reference conditions and gas type, multiplied by 1,5 shall comply with the gas leakage rate included in the documentation (see 7.4).

NOTE It is anticipated that this information may need to be provided to the end-product user for the purpose of calculating the ventilation needs.

5.4 Normal operation

Normal operation is the operation of the fuel cell module under normal conditions, in particular

- nominal power output with respect to voltage and current;
- nominal thermal energy output with respect to temperature and cooling media flow (if applicable);
- nominal temperature range of the fuel cell module;
- nominal fuel composition;
- nominal flows of anode and cathode media;
- nominal pressure ranges of anode and cathode fluids;
- rate of change of power output within the nominal ranges defined in the manufacturer's specification.

For the normal operation type test, the fuel cell module shall be operated under the normal conditions defined above until thermal equilibrium conditions are achieved.

Measurements of the following parameters shall be taken and the results recorded in the documentation as specified in 7.4:

- a) voltage at the terminals of the fuel cell module at full load current;
- b) temperatures (fuel cell stack, fuel cell module surface, ambient);
- c) fuel pressure (gauge) from –5 % to +5 % or ± 1 kPa, whichever is the higher;
- d) fuel consumption rate from –5 % to +5 %;
- e) oxidant supply from –5 % to +5 %, if applicable;
- f) oxidant pressure from –5 % to +5 % or ± 1 kPa whichever is the higher, if applicable;
- g) coolant inlet and outlet temperature (if applicable);
- h) coolant flow rate (if applicable);
- i) coolant inlet and outlet pressure (if applicable);
- j) fuel and oxidant differential pressure.

Compliance is given if, for all parameters measured, the measured values are within the manufacturer's specified values.

5.5 Allowable working pressure test

The fuel cell module shall be tested at the maximum or minimum operating temperature, whichever is more severe.

During this test, the fuel and air sides of the fuel cell module may be interconnected if they are of the same internal pressure under normal operation. If the fuel cell module comprises a cooling system, this system may be over-pressure tested simultaneously and in the same way.

The fuel cell module (both anode and cathode channels) shall be pressurized gradually and held steady for a period of not less than 1 min to no less than 1,3 times their allowable working pressure.

If the fuel cell module comprises a pressure relief valve, it may be removed or made inoperable.

This test may be conducted during the gas leakage test or the normal operating test, provided that the test parameters can be achieved.

If the test conditions (temperature) cannot be achieved, the fuel cell module shall be tested at ambient temperature at not less than 1,5 times the allowable working pressure.

There shall be no rupture, fracture, permanent deformation or other physical damage to the fuel cell module.

5.6 Pressure withstanding test of cooling system

This test shall be performed if the cooling system is not tested during the allowable working pressure test.

The fuel cell module shall be tested at the same temperature as in the allowable working pressure test.

The cooling system of the fuel cell module shall be pressurized to 1,3 times the allowable working pressure of the cooling system, and then maintained for a period of not less than 10 min.

If the test conditions (temperature) cannot be achieved, the cooling system shall be tested at ambient temperature at 1,5 times the allowable working pressure of the cooling system.

There shall be no rupture, fracture, permanent deformation or other physical damage to the system. If the system utilizes a liquid coolant, there shall be no leakage of coolant during this test.

5.7 Continuous and short-time electrical rating

Where a manufacturer specifies a short-time current rating, the fuel cell module shall be stabilized at rated current, then the current increased to the defined short-time rating and held for the defined time, as specified by the manufacturer.

There shall be no rupture, fracture, permanent deformation or other physical damage to the system.

5.8 Overpressure test

Where the fuel cell module has a pressure-limiting device, the pressure shall be increased step by step to a value that exceeds the threshold pressure of the pressure-limiting device. If necessary, the fuel cell module inlet pressure regulator shall be disabled or bypassed for this

test. The safety mechanism shall trigger a reduction in the pressure or transfer the fuel cell module into a safe operational state.

In case of a leak before break design, this test may be destructive and may be performed under 5.13. The data of this test shall be reported to the systems integrator as shall all consequential hazards.

5.9 Dielectric strength test

Fuel cell modules can be manufactured according to two different designs:

- a) stack grounded;
- b) stack floating.

For design a), no dielectric withstand test can be applied, only the open-circuit voltage appears.

For design b), the dielectric strength test shall be applied at operating temperature, and with cooling media applied. If the fuel cell module cannot be maintained at operating temperature, the dielectric strength test shall be carried out at the maximum admissible temperature and the temperature shall be recorded. If the dielectric strength test is applicable, it shall be performed on the fully assembled fuel cell module, disconnected from the fuel supply and purged with purging gas. The test voltage shall be applied between live parts and non current-carrying metal parts. The test shall be performed either with a DC or an AC voltage of substantially sinusoidal waveform at a frequency between 48 Hz and 62 Hz. The voltage shall be increased steadily to the specified value and then maintained for at least 5 s. The results are acceptable if there is no breakdown of the insulation. The leakage current shall not exceed 1 mA multiplied by the ratio of the test voltage to the open circuit voltage. If this value cannot be met, the data of this test shall be provided to the systems integrator. All consequential hazards shall be mitigated by the systems integrator.

NOTE Dependent on the final application, a test duration over 5 s might be required.

The test voltages shall be as mentioned in Table 1.

Table 1 – Dielectric strength test voltages
(derived from EN 50178)

Column 1 Open-circuit voltage	Column 2 Test voltage, AC and DC, for testing circuits with basic insulation and circuits with protective separation		Column 3 Test voltage, AC and DC, for testing between circuits and accessible surface (non-conductive or conductive but not connected to protective earth)	
	AC r.m.s. kV	DC kV	AC r.m.s. kV	DC kV
$\leq 50 \sqrt{2} \text{ V} = 71 \text{ V}$	0,35	0,5	0,35	0,5
$100 \sqrt{2} \text{ V} = 141 \text{ V}$	0,5	0,7	0,7	1,0
$150 \sqrt{2} \text{ V} = 212 \text{ V}$	0,8	1,1	1,3	1,8
$230 \sqrt{2} \text{ V} = 325 \text{ V}$	1,1	1,6	1,8	2,5
$300 \sqrt{2} \text{ V} = 424 \text{ V}$	1,2	1,7	2,2	3,1
$400 \sqrt{2} \text{ V} = 566 \text{ V}$	1,35	1,9	2,6	3,7
$600 \sqrt{2} \text{ V} = 849 \text{ V}$	1,65	2,3	3,5	5,0
$690 \sqrt{2} \text{ V} = 976 \text{ V}$	1,8	2,5	3,8	5,4
$1 \sqrt{2} \text{ kV} = 1,41 \text{ kV}$	2,25	3,2	5,0	7,1
$1,5 \sqrt{2} \text{ kV} = 2,12 \text{ kV}$	3,0	4,2	6,4	9,1
$3 \sqrt{2} \text{ kV} = 4,24 \text{ kV}$	5,25	7,4	11,2	15,8
$6 \sqrt{2} \text{ kV} = 8,4 \text{ kV}$	9,75	13,8	17,5	24,8
$10 \sqrt{2} \text{ kV} = 14,14 \text{ kV}$	15,75	22,3	34,0	48,1

NOTE Interpolation is permitted throughout all ranges.

5.10 Differential pressure test

For fuel cell modules that maintain different channels for the anode and the cathode within the module, the differential test is applicable. The fuel cell module shall be at the maximum or minimum operating temperature, whichever is more severe. The fuel cell module shall be gradually pressurized with an appropriate gas, either on the anode or cathode channels, and held steady for a period of not less than 1 min to no less than 1,3 times the allowable differential working pressure. If the test conditions cannot be achieved, the fuel cell module may be tested at ambient temperature at not less than 1,5 times the allowable working pressure.

The leakage rate shall be measured, for example with a flow rate meter either continuously during the test, or, if not possible, before and after pressurization at the allowable differential working pressure.

There shall be no rupture, fracture, permanent deformation or other physical damage to the fuel cell module. The leakage rate between anode and cathode side shall not increase as a result of this test and shall be within the manufacturer's specification for the temperature of the test. The measurements after pressurization shall not deviate from the initial results by more than the accuracy and repeatability of both, the instrumentation and the test set-up. This test may be omitted, if any excessive differential pressure cannot be exerted on the cells by design.

5.11 Gas leakage test (repeat)

The fuel cell module shall be re-tested for leakage without the pre-conditioning period, but at the same testing conditions as specified in 5.3.

The gas leakage rate shall not exceed that specified by the manufacturer, and not change by more than 10 % of the initial value or 5 cm³/min, whichever is higher.

5.12 Normal operation (repeat)

The normal operation test shall be repeated as defined in 5.3. The measurements recorded shall be within the rated deviations as required in 5.3.

5.13 Flammable concentration test

This test is only applicable for enclosed systems, with integrated safety ventilation and purging processes, where the operating temperature is below the auto-ignition temperature of the combustible gas.

Safety ventilation and purging processes depend on the specific features and requirements of the fuel cell module. This test shall determine the maximum flammable gas concentration within the module enclosure under normal operation.

The fuel cell module shall be operated within the nominal temperature range until thermal equilibrium conditions are achieved. The testing shall be carried out at the barometric pressure at the testing station and in an area free from appreciable draughts.

The fuel cell module enclosure shall be provided with the specified ventilation flow rate (see 7.4).

Four measurements shall be made at a distance from the purge or points of release so that the flammable concentration measured is that of the compartment rather than the source.

The test shall be continued until four consecutive measurements have shown that the increase in the flammable concentration does not exceed by more than 5 % the mean of the four measurements.

The time interval between measurements shall be not less than 30 min.

The test shall be carried out at least twice.

The test is satisfactory if the concentration of flammable gas is less than 25 % of the lower flammability limit. Where the concentration exceeds 25 % of the lower flammability limit, the provisions of 4.2.9 shall apply.

5.14 Tests of abnormal conditions

5.14.1 General

The purpose of type tests under abnormal operating conditions is to demonstrate that abnormal operating conditions, which can be predicted, do not result in hazard or damage outside the fuel cell module. Due to abnormal conditions, these tests may be destructive and they should be performed following the “normal” type tests. It is also acceptable to perform these tests on a sub-module of the fuel cell module, which will yield prototypical responses. The sequence of the tests of abnormal conditions may be different from type to type of fuel cell module; the sequence shall be ordered along the lines of increasing danger of destruction by the different test articles.