

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Fuel cell technologies –
Part 5-100: Portable fuel cell power systems – Safety**

**Technologies des piles à combustible –
Partie 5-100: Systèmes à piles à combustible portables – Sécurité**



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CONTENTS

FOREWORD.....	6
1 Scope	8
2 Normative references	10
3 Terms and definitions	13
4 Design and construction requirements	18
4.1 Physical environment and operating conditions	18
4.1.1 General requirements	18
4.1.2 Electrical power input	18
4.1.3 Handling, transportation, and storage	18
4.2 Material compatibility	18
4.2.1 General requirements for material compatibility	18
4.2.2 Polymeric and elastomeric components	19
4.2.3 Fuel connection devices	19
4.3 Protection against mechanical hazards	19
4.4 Protection against toxicity of fuels and fuel feedstocks	20
4.5 Protection against explosion hazards	20
4.5.1 General requirements for protection against explosion hazards	20
4.5.2 Flammable atmospheres within the portable fuel cell power system	20
4.5.3 Normal operation	20
4.5.4 Abnormal operation	20
4.5.5 Purging	20
4.5.6 Electrostatic discharge	21
4.6 Protection against electric shock	21
4.6.1 General requirements for protection against electric shock	21
4.6.2 Protection against direct contact with live parts	21
4.6.3 Protection against indirect contact with live parts	22
4.6.4 Protection by the use of SELV	22
4.7 Selection of electrical components and equipment	23
4.7.1 Area classification and suitability	23
4.7.2 Turning moments	23
4.7.3 Fuses	23
4.7.4 Capacitor discharge	23
4.7.5 Securing of parts	23
4.7.6 Current-carrying parts	24
4.7.7 Internal wiring	24
4.7.8 Cord-connected portable fuel cell power systems	24
4.7.9 Strain relief	25
4.7.10 Creepage and clearances	25
4.7.11 Separation of circuits	25
4.7.12 Protection of receptacles	26
4.7.13 Earthing and bonding	26
4.8 Protection against fire hazard	26
4.8.1 General intent and purpose of protection against fire hazard	26
4.8.2 Flammability	26
4.8.3 Openings in equipment	27
4.9 Protection against temperature hazards	28
4.9.1 General requirements for protection against temperature hazards	28

4.9.2	Surface temperatures	28
4.9.3	Component temperatures	28
4.9.4	Wall, floor and ceiling temperatures	28
4.10	Protection against electromagnetic disturbances	28
4.11	Hazard and risk assessment	28
4.11.1	General requirements for hazard and risk assessment and the approach	28
4.11.2	Safety and reliability analysis	29
4.12	Safety control circuits	29
4.13	Protection against oxygen depletion	29
4.14	Emission of effluents	30
4.15	Fuel supply	30
4.16	Fuel processing systems (if applicable)	30
4.17	Enclosures	31
4.17.1	General requirements for all enclosures	31
4.17.2	Enclosure requirements for outdoor use	31
4.18	Battery supplies	31
4.18.1	General requirements for batteries	31
4.18.2	Battery compartments	31
4.18.3	Vented wet cell batteries	32
4.18.4	Ventilation of battery compartments	32
4.19	Pressure vessels and piping	32
4.19.1	General requirements for pressure vessels and piping	32
4.19.2	Piping systems	32
4.20	Hoses	33
4.21	Automatic shut-off valves	33
4.22	Regulators	33
4.23	Process control equipment	33
4.24	Filters	33
4.24.1	Air filters	33
4.24.2	Liquid fuel filters	34
4.25	Motors	34
4.26	Fuel pumps	34
5	Instructions	34
5.1	Operation and maintenance manual	34
5.2	User's information manual	36
5.2.1	User's information manual general requirements	36
5.2.2	User's information manual front cover	36
5.2.3	Users information manual safety section	36
6	Labelling	37
6.1	General labelling requirements	37
6.2	Marking	37
6.3	Warnings	38
7	Type tests	38
7.1	General requirements for type tests	38
7.2	Tests sequence	39
7.3	Leakage test for liquid fueled systems	39
7.3.1	General requirements for leakage tests for liquid fueled systems	39
7.3.2	Method of test	39
7.4	Flammable fuel gas concentration test	40

7.4.1	General requirements for flammable gas concentration testing	40
7.4.2	Method of test.....	40
7.5	Surface temperature test.....	40
7.6	Component temperature test.....	40
7.7	Wall, floor and ceiling temperatures test	40
7.8	Dielectric strength test	41
7.8.1	General requirements for dielectric strength and testing	41
7.8.2	Test method	41
7.9	Humidity test.....	41
7.10	Leakage current at operating temperature.....	41
7.10.1	Leakage current testing requirement and duration	41
7.10.2	Test method	42
7.11	Abnormal operation testing	42
7.11.1	Abnormal operation testing – General requirements.....	42
7.11.2	Abnormal operation tests – Outcomes and further testing requirements.....	42
7.11.3	Abnormal operation test methods	42
7.12	Strain relief test	43
7.13	Insulating material test.....	43
7.14	Earthing test	43
7.15	Tank pressure test	43
7.16	Stability.....	44
7.17	Impact test.....	44
7.18	Free drop test	45
7.19	Adhesion and legibility of marking materials.....	46
7.20	Flammable gas accumulation	46
7.20.1	Flammable gas accumulation test basis and applicability.....	46
7.20.2	Test set-up	47
7.20.3	Test method	47
7.21	Oxygen depletion test	47
7.21.1	Oxygen depletion test basis and applicability.....	47
7.21.2	Test set-up	47
7.21.3	Test method	48
7.22	Emission of effluents tests	48
7.22.1	Emission of effluents testing sequence	48
7.22.2	Emission of effluents for indoors.....	48
7.23	Wind test	50
7.23.1	Wind test applicability	50
7.23.2	Method of test.....	50
7.24	Strength test	51
7.24.1	Strength test sequencing and alternative compliance methods	51
7.24.2	Method of test (liquid).....	51
7.24.3	Method of test (gas).....	51
7.24.4	Passing criteria.....	51
7.25	Stress relief test.....	52
7.26	Fuel supply securement test	52
7.27	Shutdown parameters	52
7.28	Non-metallic tubing conductivity test	52
7.28.1	Passing criteria.....	52
7.28.2	Test method	52

7.29	Non-metallic tubing test for accumulation of static electricity.....	53
7.29.1	Passing criteria.....	53
7.29.2	Test method	53
8	Routine tests	53
8.1	Routine test requirements	53
8.2	Liquid leakage test.....	53
8.3	Gas leakage test.....	53
8.4	Dielectric strength test	54
8.5	Routine test records.....	54
Annex A	(normative) Ventilation rates for batteries	55
A.1	Ventilation rate for valve regulated lead acid batteries	55
A.2	Ventilation rate for vented wet cell batteries.....	55
Annex B	(informative) Shock and vibration limits for high shock environments	56
B.1	Field of application.....	56
B.2	Vertical axis test	56
B.3	Longitudinal and lateral axes tests	56
Annex C	(normative) Uncertainty of measurements	58
Bibliography		59
Figure 1	– Portable fuel cell power systems	9
Figure 2	– Articulated probe.....	46
Table 1	– Emission limits based on STEL	50
Table B.1	– Vertical axis vibration conditions	56
Table B.2	– Longitudinal and lateral axes vibration conditions	57
Table C.1	– Measurements and their maximum uncertainties.....	58

INTERNATIONAL ELECTROTECHNICAL COMMISSION

FUEL CELL TECHNOLOGIES –

Part 5-100: Portable fuel cell power systems – Safety

FOREWORD

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International Standard IEC 62282-5-100 has been prepared by IEC technical committee 105: Fuel cell technologies.

This edition cancels and replaces the second edition of IEC 62282-5-1, published in 2012. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to IEC 62282-5-1:

- the requirements and verification method regarding 4.13 and 7.21 for oxygen depletion have been modified;
- the requirements and verification method regarding 4.14 and 7.22 for emission of effluents have been modified;
- Subclauses 4.21 and 7.20.3, for fuel cell power systems with flammable gas generators relying on water reactive technology, new safety requirements and test procedures have been added;
- Subclause 7.11.1 e) has been updated; for an overcurrent test in abnormal operations, a new test procedure in consideration of safety has been added.

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

CDV	Report on voting
105/649/CDV	105/670/RVC

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.

FUEL CELL TECHNOLOGIES –

Part 5-100: Portable fuel cell power systems – Safety

1 Scope

This part of IEC 62282 covers construction, marking and test requirements for portable fuel cell power systems. These fuel cell systems are movable and not fastened or otherwise secured to a specific location. The purpose of the portable fuel cell power system is to produce electrical power.

This document applies to AC and DC type portable fuel cell power systems, with a rated output voltage not exceeding 600 V AC, or 850 V DC for indoor and outdoor use. These portable fuel cell power systems cannot be used in hazardous locations as defined in IEC 60050-426:2008, 426-03-01 unless there are additional protective measures in accordance with IEC 60079-0[5]¹⁾.

This document does not apply to portable fuel cell power systems that are

- 1) permanently connected (hard wired) to the electrical distribution system,
- 2) permanently connected to a utility fuel distribution system,
- 3) exporting power to the grid,
- 4) for propulsion of road vehicles,
- 5) intended to be used on board passenger aircraft.

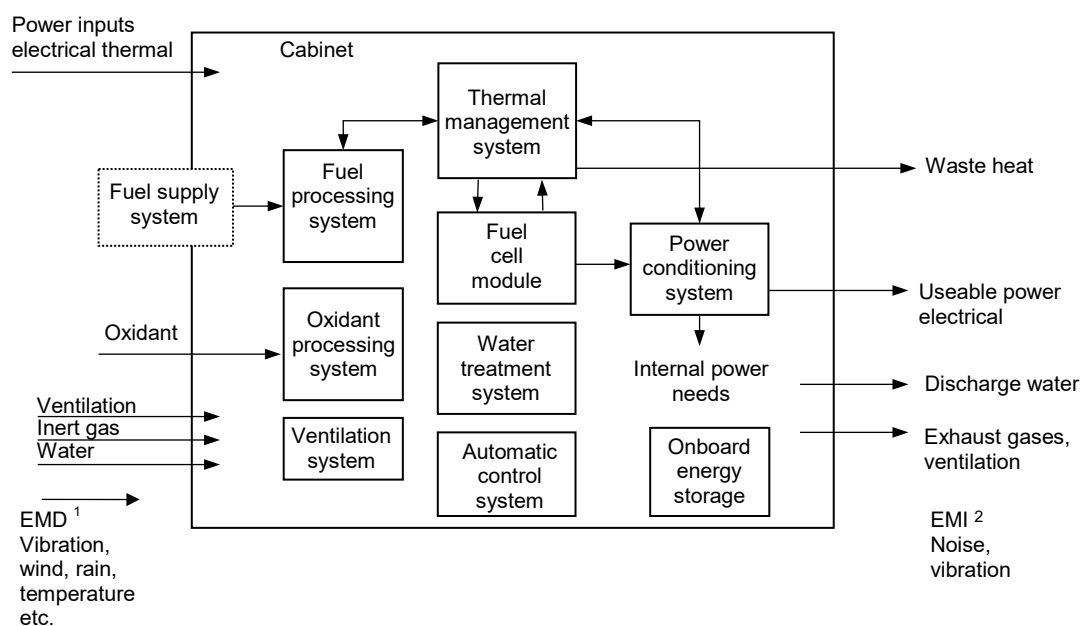
Fuel cells that provide battery charging for hybrid vehicles where the battery provides power and energy for propulsion of the vehicle are not included in the scope of this document

The following fuels and fuel feedstocks are considered within the scope of this document:

- natural gas,
- liquefied petroleum gas, such as propane and butane,
- liquid alcohols, for example methanol, ethanol,
- gasoline,
- diesel,
- kerosene,
- hydrogen,
- chemical hydrides.

This document does not preclude the use of similar fuels or oxidants from sources other than air provided the unique hazards are addressed through additional requirements.

1) Numbers in square brackets refer to the Bibliography.



IEC

Key1 EMD¹ electromagnetic disturbance2 EMI² electromagnetic interference**Figure 1 – Portable fuel cell power systems**

The overall design of a portable fuel cell power system anticipated by this document forms an assembly of some or all of the following systems (see Figure 1), integrated as necessary, to perform designated functions, as follows:

Fuel processing system – chemical processing equipment including any associated heat exchangers and controls required to convert input fuel to a composition suitable for the fuel cell stack.

Oxidant processing system – subsystem that meters, conditions, processes and may pressurize the incoming oxidant supply for use within the fuel cell power system.

Thermal management system – subsystem intended to provide cooling and heat rejection in order to maintain thermal equilibrium within the fuel cell power system, and, if necessary, to provide for the recovery and utilization of excess heat and to assist in heating the fuel cell power systems during start-up.

Power conditioning system – equipment which is used to change the magnitude or waveform of the voltage, or otherwise alter or regulate the output of a power source.

Automatic control system – assembly of sensors, actuators, valves, switches and logic components (including process controllers) that maintains the fuel cell power system parameters within the manufacturer's specified limits without manual intervention.

Fuel cell module – assembly, including a fuel cell stack(s), which electrochemically converts chemical energy to electric energy and thermal energy intended to be integrated into a power generation system.

Fuel supply system – either integral to the portable fuel cell power system or supplied through a removable and refillable container assembly.

On-board energy storage system – an internal energy source intended to aid or complement the fuel cell module in providing power to internal or external loads.

Ventilation systems – subsystem of the fuel cell power system that provides, by mechanical means, air to its cabinet.

Water treatment systems – provides for treatment and purification of recovered or added water for use within the portable fuel cell power system.

These requirements are not intended to prevent the design and construction of a portable fuel cell power system not specifically described in this document, provided that such alternatives have been considered and equivalent testing yields equivalent safety performance to that specified in this document. In considering alternative designs or construction, this document can be used to evaluate the alternative materials or methods to be used as to their ability to yield equivalent performance to that specified in this document.

This document does not cover requirements of pressurized or non-pressurized fuel supply containers upstream of the appliance gaseous or liquid fuel supply connector that are not integral to the portable fuel cell power system.

All pressures in this document are considered to be gauge pressures, unless otherwise specified.

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 60034 (all parts), *Rotating electrical machines*

IEC 60068-2-75, *Environmental testing – Part 2-75: Tests – Test Eh: Hammer tests*

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 60079-15, *Explosive atmospheres – Part 15: Equipment protection by type of protection "n"*

IEC 60079-29 (all parts), *Explosive atmospheres – Part 29: Gas detectors*

IEC 60086-4, *Primary batteries – Part 4: Safety of lithium batteries*

IEC 60204-1:2016, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60216-4-1, *Electrical insulating materials – Thermal endurance properties – Part 4-1: Ageing ovens – Single-chamber ovens*

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

IEC 60335-1:2010/AMD1:2013

IEC 60335-1:2010/AMD2:2016

IEC 60364-4-41, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

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

IEC 60695-2-11, *Fire hazard testing – Part 2-11: Glowing/hot-wire based test methods – Glow-wire flammability test method for end-products (GWEPT)*

IEC 60695-2-13, *Fire hazard testing – Part 2-13: Glowing/hot-wire based test methods – Glow-wire ignition temperature (GWIT) test method for materials*

IEC 60695-11-5, *Fire hazard testing – Part 11-5: Test flames – Needle-flame test method – Apparatus, confirmatory test arrangement and guidance*

IEC 60695-11-10, *Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods*

IEC 60695-11-20, *Fire hazard testing – Part 11-20: Test flames – 500 W flame test method*

IEC 60730-1:2013, *Automatic electrical controls – Part 1: General requirements*
IEC 60730-1:2013/AMD1:2015

IEC 60730-2-5, *Automatic electrical controls – Part 2-5: Particular requirements for automatic electrical burner control systems*

IEC 60730-2-17, *Automatic electrical controls for household and similar use – Part 2-17: Particular requirements for electrically operated gas valves, including mechanical requirements²⁾*

IEC 60812, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*

IEC 60884-1, *Plugs and socket-outlets for household and similar purposes – Part 1: General requirements*

IEC 60934, *Circuit-breakers for equipment (CBE)*

IEC 60950-1:2005, *Information technology equipment – Safety – Part 1: General requirements*
IEC 60950-1:2005/AMD1:2009
IEC 60950-1:2005/AMD2:2013

IEC 60990:2016, *Methods of measurement of touch current and protective conductor current*

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

²⁾ Withdrawn.

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 61025, *Fault tree analysis (FTA)*

IEC 61032, *Protection of persons and equipment by enclosures – Probes for verification*

IEC 61508-1, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements*

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

IEC 61511-3, *Functional safety – Safety instrumented systems for the process industry sector – Part 3: Guidance for the determination of the required safety integrity levels*

IEC 61882, *Hazard and operability studies (HAZOP studies) – Application guide*

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

IEC 62040-2, *Uninterruptible power systems (UPS) – Part 2: Electromagnetic compatibility (EMC) requirements*

IEC 62133 (all parts), *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications*

IEC 62282-2, *Fuel cell technologies – Part 2: Fuel cell modules*

ISO 3864 (all parts), *Graphical symbols – Safety colours and safety signs*

ISO 7000, *Graphical symbols for use on equipment* (available at <http://www.graphical-symbols.info/equipment>)

ISO 7010, *Graphical symbols – Safety colours and safety signs – Registered safety signs*

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

ISO 16000-3, *Indoor air – Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air – Active sampling method*

ISO 16000-6, *Indoor air – Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS or MS-FID*

ISO 16017-1:2000, *Indoor, ambient and workplace air – Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography – Part 1: Pumped sampling*

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

ISO 16528 (all parts), *Boilers and pressure vessels*

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

basic insulation

insulation of hazardous-live-parts which provides basic protection

[SOURCE: IEC 60050-195:1998, 195-06-06, modified – The note has been deleted.]

3.2

double insulation

insulation comprising both basic insulation and supplementary insulation

[SOURCE: IEC 60050-195:1998, 195-06-08]

3.3

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 only applies to the French language.

[SOURCE: IEC 60050-161:1990, 161-01-06, modified – The notes have been deleted.]

3.4

electromagnetic disturbance

EMD

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

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

[SOURCE: IEC 60050-161:1990, 161-01-05, modified – The note has been deleted.]

3.5

enclosure

housing affording the type and degree of protection suitable for the intended application

Note 1 to entry: One type of enclosure can be inside another type (e.g. an electrical enclosure inside a fire enclosure or a fire enclosure inside an electrical enclosure). Also, a single enclosure can provide the functions of more than one type (e.g. those of both an electrical enclosure and a fire enclosure). Enclosures may be electrical, mechanical, fire or another type of enclosure to provide protection from these hazards or from wind, weather and other hazards.

[SOURCE: IEC 60050-195:1998, 195-02-35, modified – The note has been added.]

3.6

electrical enclosure

enclosure providing protection against the foreseen dangers created by electricity

[SOURCE: IEC 60050-195:1998, 195-06-13]

3.7

fire enclosure

part of the equipment intended to minimize the spread of fire or flames from within

3.8

mechanical enclosure

part of the equipment intended to reduce the risk of injury due to mechanical and other physical hazards

3.9

hazardous location

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

3.10

explosive atmosphere

mixture with air, under atmospheric conditions, of flammable substances in the form of gas, vapour, dust, fibres, or flyings which, after ignition, permits self-sustaining propagation

[SOURCE: IEC 60050-426:2008, 426-01-06]

3.11

hazardous energy level

available power level of 240 VA or more, having a duration of 60 s or more, or a stored energy level of 20 J or more (for example, from one or more capacitors), at a potential of 2 V or more

[SOURCE: IEC 60950-1:2005, 1.2.8.10]

3.12

hazardous voltage

voltage exceeding 42,4 V peak, or 60 V DC, existing in a circuit that does not meet the requirements for either a limited current circuit or a TNV circuit

[SOURCE: IEC 60950-1:2005, 1.2.8.6]

3.13

heat deflection temperature

HDT

measure of a polymer's resistance to distortion under a given load at elevated temperatures

Note 1 to entry: The deflection temperature is the temperature at which a test bar, loaded to the specified bending stress, deflects by 0,25 mm.

Note 2 to entry: This note only applies to the French language.

3.14

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.

Note 2 to entry: This note only applies to the French language.

3.15**limited current circuit**

circuit that is so designed and protected that, under both normal operating conditions and single fault conditions, the current that can be drawn is not hazardous

Note 1 to entry: The limit values of currents under normal operating conditions and single fault conditions (see IEC 60950-1:2005, 1.4.14) are specified in IEC 60950-1:2005, 2.4.

[SOURCE: IEC 60950-1:2005, 1.2.8.9]

3.16**live part**

conductor or conductive part intended to be energized in normal operation, including a neutral conductor, but by convention not a PEN conductor or PEM conductor or PEL conductor

Note 1 to entry: This concept does not necessarily imply a risk of electric shock.

[SOURCE: IEC 60050-195:1998, 195-02-19]

3.17**maximum allowable working pressure****MAWP**

maximum pressure at which a fuel cell or fuel cell power system may be operated

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

Note 2 to entry: The maximum allowable working pressure is the pressure used in determining the setting of pressure limiting and relieving devices installed to protect a component or system from accidental over-pressuring.

Note 3 to entry: For the purposes of this document, all pressures are to be given and used as gauge pressures unless absolute pressure is indicated.

Note 4 to entry: This note only applies to the French language.

3.18**maximum operating pressure**

maximum pressure, specified in gauge pressure 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: This includes all normal operation, both steady state and transient.

3.19**operator access area**

area for which under normal operating conditions

- a) access is gained without the use of a tool; or
- b) the means of access is deliberately provided to the operator; or
- c) the operator is instructed to enter regardless of whether or not tools are needed to gain access

Note 1 to entry: In this document, the terms "access" and "accessible", unless qualified, relate to operator access as defined above.

3.20**portable fuel cell power system**

fuel cell power system that is not intended to be permanently fastened or otherwise secured in a specific location

3.21**portable stand-alone fuel cell power system**

portable fuel cell power system that is not designed to be connected to the energized mains

3.22

reinforced insulation

insulation of hazardous-live-parts which provides a degree of protection against electric shock equivalent to double insulation

Note 1 to entry: Reinforced insulation may comprise several layers which cannot be tested singly as basic insulation or supplementary insulation.

[SOURCE: IEC 60050-195:1998, 195-06-09]

3.23

secondary circuit

circuit that has no direct connection to a primary circuit and derives its power from a transformer, converter or equivalent isolation device, or from a battery

Note 1 to entry: Conductive parts of an interconnecting cable may be part of a secondary circuit as stated in IEC 60950-1:2005, 1.2.11.6.

[SOURCE: IEC 60950-1:2005, 1.2.8.5]

3.24

SELV

safety extra low voltage

voltage, the peak value of which does not exceed 42,4 V for alternating current and which does not exceed 60 V for direct current

Note 1 to entry: When safety extra low voltage is obtained from the supply mains, it is to be through a safety isolating transformer or a converter with separate windings, the insulation of which complies with double insulation or reinforced insulation requirements.

Note 2 to entry: The voltage limits specified are based on the assumption that the safety isolating transformer is supplied at its rated voltage.

[SOURCE: IEC 60335-1:2010, 3.4.2, modified – The definition has been revised.]

3.25

SELV circuit

safety extra low voltage circuit

secondary circuit that is so designed and protected that under normal operating conditions and single fault conditions, its voltages do not exceed a safe value

Note 1 to entry: For commercial, industrial and telecommunication applications, the SELV voltage limits provided in IEC 60950-1:2005 are applicable. For household applications, the SELV voltage limits in IEC 60335-1:2010 shall be used.

Note 2 to entry: The limit values of voltages under normal operating conditions and single fault conditions (see IEC 60950-1:2005, 1.4.14) are specified in IEC 60950-1:2005, 2.2. See IEC 60950-1:2005, Table 1.A.

Note 3 to entry: This definition of a SELV circuit differs from the term "SELV system" as used in IEC 61140.

[SOURCE: IEC 60950-1:2005, definition 1.2.8.8, modified – Note 1 has been added.]

3.26

service personnel

trained persons having familiarity and experience with the construction and operation of the system and the risks involved

3.27

standard litre

volume in litre at temperature of 288,15 K (15 °C) and pressure of 101,325 kPa

3.28**supplementary insulation**

independent insulation applied in addition to basic insulation in order to reduce the risk of electric shock in the event of a failure of the basic insulation

3.29**thermal equilibrium**

stable temperature conditions, pseudo steady-state, arbitrarily indicated by temperature changes of no more than 3 K or 1 % of the absolute operating temperature, whichever is higher between two readings 15 min apart

3.30**tool**

screwdriver, coin, key, or any other object that may be used to operate a screw, latch, or similar fastening means

3.31**touch voltage**

voltage between conductive parts when touched simultaneously by a person or an animal

Note 1 to entry: The value of the effective touch voltage may be appreciably influenced by the impedance of the person or the animal in electric contact with these conductive parts.

3.32**uninterruptible power system****UPS**

combination of convertors, switches and energy storage devices (for example, batteries), constituting a power system for maintaining continuity of load power in case of input power failure

3.33**wet cell battery**

battery in which the electrolyte is in liquid and mobile form

3.34**transportable equipment**

movable equipment that is intended to be routinely carried by a user

Note 1 to entry Examples include laptop and notebook personal computers, pen-based tablet computers, and their portable accessories such as printers and CD-ROM drives.

[SOURCE: IEC 60950-1:2005, 1.2.3.3]

3.35**hand-supported equipment**

equipment that is physically supported by any part of the body of the user during the performance of its intended functions

3.36**hand-held equipment**

portable and intended to be held in the hand during normal use

[SOURCE: IEC 60050-151:2001, 151-16-48, modified – "equipment" has been added.]

3.37**highly ventilated area**

area that is provided with clean, fresh air at a minimum flow rate of 140 m³/h (approximately 10 air changes per hour in a room of 14 m³)

Note 1 to entry: Different ventilation rates may be used. See 4.14.

3.38

PEN conductor

conductor combining the functions of both a protective earthing conductor and a neutral conductor

[SOURCE: IEC 60050-195:1998, 195-02-12]

3.39

PEM conductor

conductor combining the functions of both a protective earthing conductor and a mid-point conductor

[SOURCE: IEC 60050-195:1998, 195-02-13]

3.40

PEL conductor

conductor combining the functions of both a protective earthing conductor and a line conductor

[SOURCE: IEC 60050-195:1998, 195-02-14]

4 Design and construction requirements

4.1 Physical environment and operating conditions

4.1.1 General requirements

The portable fuel cell system and its protective systems shall be so designed and constructed as to be capable of performing their intended functions in their expected physical environment and operating conditions.

4.1.2 Electrical power input

The fuel cell power system input limits shall be designed to operate correctly with the conditions of IEC 60204-1:2016, 4.3 or as otherwise specified by the manufacturer.

4.1.3 Handling, transportation, and storage

The portable 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. The fuel cell power system or each component part thereof shall be packaged or designed so that it can be stored safely and without damage (e.g. adequate stability, special supports).

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

4.2 Material compatibility

4.2.1 General requirements for material compatibility

All parts and all substances used shall be suitable for the range of temperatures and pressures to which they are subjected during expected usage; and suitably resistant to the reactions, processes, environments and other conditions to which they are exposed during expected usage. The following provisions apply.

- 1) Appropriate pressure relief devices or methods shall be used to protect parts from damage due to overpressure as indicated by the safety and reliability analysis carried out in accordance with 4.11. Pressure relief devices or methods shall be used to prevent the system, or portions of the system, from exceeding the maximum allowable working pressure of the system, or portion of the system.

- 2) Any part that is exposed directly to liquid fuel, moisture, condensate, etc. as well as fasteners used to attach any part that needs to be adjusted or removed for servicing, shall be corrosion-resistant and suitable for the application.
- 3) Ferrous materials used in the construction of the outside casing, and in an outside cabinet which is the sole enclosure of current-carrying parts, shall be adequately protected against corrosion.
- 4) Asbestos or asbestos-containing material(s) shall not be used in the construction of a portable fuel cell power system.

4.2.2 Polymeric and elastomeric components

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

- 1) Materials shall be demonstrated to be suitable for the combined maximum operating temperatures and pressures and compatible with other materials and chemicals with which they will come into contact in normal operation, service and maintenance over the manufacturer-defined life span of the product. Guidance can be found in ISO 4080.
- 2) Polymeric or elastomeric components shall be protected from mechanical damage within the enclosure. Shielding may be used as appropriate to protect components against failure of rotating equipment or other mechanical devices housed within the portable fuel cell power system.
- 3) Any compartment enclosing polymeric or elastomeric components used to convey flammable gases shall be protected against the possibility of overheating. A control system shall be provided to terminate fuel flow before temperatures reach 10 °C below the lowest heat deflection temperatures (HDT) of the materials used in the fuel conveying components.
- 4) Non-metallic tubing may be used if it is demonstrated through testing that the end-to-end resistance is less than 1 MΩ, at a test voltage up to 1 000 V, when measured between two metal fittings and provided that at least one end of the tubing is connected to a metal fitting that is electrically continuous with the equipment frame and other associated metal parts are bonded such that discharges through air cannot occur (see IEC 60079-32 (all parts) [7]). Air gaps less than 1 cm between a semi-conductive tubing wall and other metal parts are not permissible. Compliance is determined through the conductivity test of 7.29.

Alternatively, the non-metallic tubing may be tested using the accumulation of static electricity test of 7.30 to determine that under normal and abnormal operating conditions including refuelling, an incentive electrostatic charge on the tubing material would not be generated as a result of fluid flow through the tubing.

- 5) Appropriate pressure relief devices or methods shall be used to protect polymeric and elastomeric components from damage due to overpressure as indicated by the safety and reliability analysis carried out in accordance with 4.11.

4.2.3 Fuel connection devices

Fuel connection devices shall be resistant to stress corrosion cracking.

NOTE Guidance can be found in ISO 15156-1 [13].

4.3 Protection against mechanical hazards

Protection shall be provided against accidental contact with moving parts. All parts that may be contacted during normal usage, adjustment or servicing shall be free from sharp projections or edges.

The portable fuel cell power systems shall resist reasonably foreseeable impacts and not be susceptible to tipping during operation and handling. Compliance is demonstrated through the type tests in 7.16, 7.17, and 7.18.

4.4 Protection against toxicity of fuels and fuel feedstocks

Precautions shall be taken in the design of the portable fuel cell power system and fuel supply to avoid spillage or unnecessary exposure of personnel to fuels that are potentially harmful due to flammability, corrosive effects, ingestion, inhalation or skin absorption.

The operating and storage instructions shall describe the possible hazards resulting from the use of fuels and any precautions to be taken when handling the materials. This shall include the maximum tolerable exposure levels in continuous use, and means to deal with spillage or contamination of personnel.

4.5 Protection against explosion hazards

4.5.1 General requirements for protection against explosion hazards

The portable fuel cell power system shall be designed and constructed to minimize the risk of fire or explosion posed by the portable fuel cell power system itself, or by gases, liquids, dust, vapours or other substances produced or used by the portable fuel cell power system.

4.5.2 Flammable atmospheres within the portable fuel cell power system

Within the portable fuel cell power system, compartments with sources of flammable gas or vapour shall be classified and the extent of hazardous areas determined. The boundary for dilution to below 25 % of the lower flammability limit (LFL) may be determined by computational fluid dynamics analysis, tracer gas, or similar methods such as those given in IEC 60079-10 (all parts) or IEC 60079-2.

Within areas classified as hazardous, the manufacturer shall eliminate ignition sources by ensuring that:

- the installed electrical equipment is suitable for the area classification;
- the surface temperatures do not exceed 80 % of the auto-ignition temperature, expressed in degrees Celsius, of the flammable gas or vapour; see ISO/IEC 80079-20-1 for guidance regarding auto-ignition temperatures of various flammable fluids;
- the potential for static discharge has been eliminated by proper bonding and earthing;
- 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.

4.5.3 Normal operation

The concentration of fuel vapour within the system enclosure shall be less than 25 % of the LFL under normal operating conditions. Where mechanical ventilation is required to meet a safety limit or maintain the LFL limits, the portable fuel cell power system shall safely shut down in a controlled manner upon failure of the ventilation system. Compliance with this requirement is demonstrated in 7.4.

4.5.4 Abnormal operation

In the event of an internal release of flammable gas, a safety device within the portable fuel cell power system shall shut down the system immediately or prior to concentrations reaching 25 % of the LFL at the highest concentration area.

4.5.5 Purging

Means shall be provided to purge those systems of the portable fuel cell power system where, for safety reasons, it requires a passive state after shutdown or prior to initialization as specified by the manufacturer. A suitable purge system, utilizing a medium specified by the manufacturer

such as but not limited to nitrogen, or air or steam in a non-hazardous situation within the intended use, meets the intent of this provision.

If safety can be secured by procedures other than the purge, purging is not required.

4.5.6 Electrostatic discharge

Protection against electrostatic discharges shall be provided in locations where a flammable gas may accumulate. This may be achieved through the selection of materials for non-metallic tubing and through the grounding and bonding of isolated metal parts. An electrostatic test instrument shall be used to verify there is no spark-capable generation of charge during equipment operation or when re-fuelling (see 7.29 and 7.30).

Non-metallic tubing carrying fluids, such as hydrogen gas, may accumulate an electrostatic charge along its interior and exterior surfaces and it may transfer some of that charge to metal fittings attached at either end. Discharges from the external surface of this tube, or the fittings, may be sufficient to ignite a flammable mixture of gas or vapour in the surrounding environment. The accumulation of charge may be mitigated by specifying a tube material with a resistance less than 1 M Ω , at a test voltage up to 1 000 V, as measured between metal fittings on either end of the tube (see IEC 60079-32 (all parts) [7]). Alternatively, gas flow velocity may be limited to values below which electrostatic charge does not accumulate for that specific material. Metal braid coverings, or conductive wires within the non-metallic tubing, can reduce charge accumulation, but may also increase the chance of electrostatic discharge if those conductors become disconnected from their bonding conductor. Flexible metal tubing with isolating unions may be a practical alternative to the use of polymeric tubing.

4.6 Protection against electric shock

4.6.1 General requirements for protection against electric shock

Except where specifically permitted for functional reasons, accessible conductive parts of equipment shall not be hazardous live parts in normal conditions, nor be, or become, hazardous live parts in any reasonably foreseeable single fault condition. Portable fuel cell power systems shall be constructed and enclosed so that there is adequate protection against accidental contact with live parts.

The electrical equipment shall provide protection of persons against electric shock from

- 1) direct contact,
- 2) indirect contact.

4.6.2 Protection against direct contact with live parts

4.6.2.1 General requirements and alternative measures for protection against direct contact with live parts

For each circuit or part of the electrical equipment, protection shall be achieved through the use of enclosures or the insulation of live parts. Where these measures are not practical, alternative measures for protection may be applied such as barriers, placing out of reach, and using obstacles (see IEC 60364-4-41).

4.6.2.2 Protection by enclosures

Opening an enclosure (i.e. opening doors, lids, covers, and the like) shall be possible only under one of the following conditions:

- 1) the use of a key or tool;
- 2) the disconnection of live parts inside the enclosure before the enclosure may be opened (i.e., interlocking the door);

- 3) opening without using one of the protection techniques described in 1) or 2) shall be possible only when all live parts are protected against direct contact to at least IP2X or IPXXB (see IEC 60529).

4.6.2.3 Protection by insulation of live parts

It shall not be possible to touch live parts or live parts protected only by lacquer, enamel, ordinary paper, cotton, oxide film, beads, or sealing compound except self-hardening resins, with the test probe B of IEC 61032.

Live parts protected by insulation shall be completely covered with insulation that can only be removed by destruction. Such insulation shall be capable of withstanding the mechanical, chemical, electrical, and thermal stresses to which it can be subjected under normal service conditions. Heat-resistant, moisture-absorption-resistant insulating material, such as phenolic composition, porcelain, cold moulded composition that will withstand the most severe conditions likely to be met in service shall be used for the support of bare, live parts and for barriers used to obtain required spacings (as specified in 4.7.10) and shall comply with the test specified in 7.13.

4.6.3 Protection against indirect contact with live parts

4.6.3.1 General intent and acceptable approaches for protection against indirect contact with live parts

Protection against indirect contact is intended to prevent hazardous conditions in the event of an insulation failure between live parts and exposed conductive parts. Protection against indirect contact shall be achieved by measures to prevent the occurrence of a hazardous touch voltage; or automatic disconnection of the supply before the time of contact with a touch voltage can become hazardous.

4.6.3.2 Measures to prevent the occurrence of a hazardous touch voltage

Measures to prevent the occurrence of a hazardous touch voltage include the use of Class II equipment or by equivalent insulations (see IEC 61140), electrical separation (see IEC 60364-4-41) and the design of the supply system so that its neutral point is either insulated from or has a high impedance to earth so that an earth fault will not result in a hazardous touch voltage.

4.6.3.3 Automatic disconnection of the supply

Automatic disconnection of the supply of any circuit affected by the occurrence of an insulation failure is intended to prevent a hazardous condition resulting from a touch voltage (see IEC 60364-4-41).

4.6.4 Protection by the use of SELV

SELV (safety extra-low voltage) may be used to protect persons against electric shock from both direct and indirect contact. Accessible parts are not considered to be a shock hazard at or below SELV.

An accessible part is not considered to be live if the part is supplied at safety extra-low voltage, provided that:

- a) for alternating current, the peak value of the voltage does not exceed 42,4 V;
- b) for direct current, the voltage does not exceed 60 V;
- c) the part is separated from live parts by protective impedance. If protective impedance is used, the current between the part and the supply source shall not exceed 2 mA for direct current and its peak value shall not exceed 0,7 mA for alternating current as described in IEC 60335-1:2010, 8.1.4 and IEC 60990:2016, Figure 4.

4.7 Selection of electrical components and equipment

4.7.1 Area classification and suitability

Electrical components and equipment shall be suitable for the area classification in which they are used, based on IEC 60079-10 (all parts) (see 4.5.2).

4.7.2 Turning moments

Electrical components such as switches that are subjected to turning moments in normal operation or servicing shall be fastened securely and prevented from turning by means other than friction between surfaces, if turning could result in reduction of the spacings specified in 4.7.10 or 4.7.11, or in an infringement of other requirements of this document. A lock washer shall not be considered acceptable for devices that require turning moments for their operation.

4.7.3 Fuses

If the circuits protected by the fuses extend beyond the portable fuel cell power system enclosure, fuses shall be of a type that are non-replaceable without the use of tools (e.g. soldered-in type). If the circuits protected by the fuses do not extend beyond the enclosure, the fuses may be of a readily replaceable type. If the fuse can be contacted externally, a fully touch proof fuse-holder shall be used.

4.7.4 Capacitor discharge

If the charge stored in capacitors is accessible in an operator access area, and the safety of the operator is assured by an interlock actuated by a door or cover, or by disconnecting a connector (or attachment plug), then the energy stored as determined from the following equation, shall be discharged to a safe level not exceeding 42,4 V peak or DC and it shall not exceed 20 J at 1 s after operation of this interlock or disconnection of the connector:

$$J = 5 \times 10^{-7} CV^2$$

where

J is the energy in joules;

C is the capacity in microfarads;

V is the voltage in volts.

4.7.5 Securing of parts

Screws, nuts, washers, springs or similar parts shall be secured so as to withstand mechanical stresses occurring in normal use if loosening would create a hazard, or if clearances or creepage distances over supplementary insulation or reinforced insulation would be reduced to less than the values specified in 4.7.10.

Bare live parts (including conductors) shall be fixed to their bases or mounting surfaces so that they shall be prevented from turning or shifting so as to reduce the spacings required by 4.7.10. Friction between surfaces is not an acceptable means of preventing the turning of live parts, but a suitable lock washer will be acceptable if properly applied.

Compliance is checked by inspection, by measurement and by manual test.

For the purpose of assessing compliance, it is assumed that

- two independent fixings will not become loose at the same time,
- parts fixed by means of screws or nuts provided with self-locking washers or other means of locking are not liable to become loose.

4.7.6 Current-carrying parts

Current-carrying parts shall have adequate mechanical strength and current-carrying capacity for the service, and shall be non-ferrous or stainless steel, except that in SELV circuits the material is not specified.

The securement of contact assemblies shall be such as to ensure the continued alignment of contacts.

Misalignment of male and female connectors, insertion of a multi-pin male connector in a female connector other than one intended to receive it, and other manipulations of parts that are accessible without the use of a tool shall not result in a hazardous condition.

4.7.7 Internal wiring

The space within enclosures of equipment shall provide ample room for the distribution of wires and cables required for the proper wiring of the equipment to prevent overheating and damage to the insulation. The wire connections and wires between parts of equipment shall be protected or enclosed. Wireways shall be smooth and entirely free from projections, burrs, and sharp edges that may cause abrasion of the insulation on the conductors.

Wiring other than that of printed circuits shall consist of wire of a type, or types, that are suitable for the particular application when considered with respect to

- a) conductor size (consideration shall be given to the effects of vibration, impact and handling for wires smaller than 1,5 mm²);
- b) temperature and voltage to which the wiring is liable to be subjected;
- c) exposure to oil, grease or other substance liable to have a deleterious effect on the insulation;
- d) exposure to moisture;
- e) other conditions of service to which the wire is liable to be subjected.

All wiring joints shall be provided with insulation equivalent to that of the conductors themselves, unless they are held securely and rigidly so that the spacings required by 4.7.10 are maintained.

Cords and insulated conductors, either single or bunched, or cabled, when passing through openings in sheet metal walls, shall be effectively protected by suitable bushings or well-rounded bearing surfaces which shall not damage the cords or conductors.

Conductors identified by green or the colour combination green/yellow shall be used only for earthing or bonding connections.

Electrical connections which need to be broken to service any controls shall be made in such a manner that they may be disconnected and reconnected without breaking a soldered connection and without breaking or cutting the wire(s).

4.7.8 Cord-connected portable fuel cell power systems

Portable fuel cell power systems intended to be cord-connected at the input shall be provided with a suitable length of cord having an additional conductor for earthing non-current-carrying conductive parts. The cord shall have an ampacity at least equal to the marked input in amperes and shall be of the hard-usage type, damp/wet type, except as required by other clauses of this document.

The supply cord shall terminate in a suitable attachment plug that conforms to IEC 60884-1 and has

- a voltage rating suitable for the voltage marked on the portable fuel cell power system,
- a current rating of not less than 125 % of the marked input current.

4.7.9 Strain relief

Strain relief shall be provided so that stress on a supply cord, as determined by the test specified in 7.26 or twisting of the cord, will not be transmitted to the connections inside the portable fuel cell power system. Portable fuel cell power systems provided with a supply cord, or intended to be connected to fixed wiring by a flexible cord, shall have a cord anchorage. The cord anchorage shall relieve conductors from strain, including twisting, at the terminals and protect the insulation of the conductors from abrasion. At least one part of the cord anchorage shall be securely fixed to the portable fuel cell power system, unless it is part of a specially prepared cord.

At the point at which a supply cord passes through an opening in a wall, a barrier or the overall enclosure, there shall be a bushing or the equivalent that is secured in place and that has smooth, well-rounded bearing surfaces which will not damage the cord.

It shall not be possible for a flexible cord to be pushed through the cord-entry hole, if such displacement is liable to:

- 1) subject the cord to mechanical injury;
- 2) expose the cord to a temperature higher than that for which the cord is recognized;
- 3) reduce the spacings (such as from bare live parts to a metal strain relief clamp) below the values specified in 4.7.10.

4.7.10 Creepage and clearances

Portable fuel cell power systems shall be constructed so that the clearances, creepage distances and solid insulation are adequate to withstand the electrical stresses to which the portable fuel cell power system is liable to be subjected. Guidance in determining appropriate clearance and creepage distances is specified in IEC 60664-1.

Exemption: An anode and cathode of the same cell are not subject to these clearances and creepage requirements.

In the case of explosive gas atmospheres, as determined by IEC 60079-10 (all parts), the clearances, creepage distances and separations between conductive parts at different potentials shall also comply with IEC 60079-15.

4.7.11 Separation of circuits

Insulated conductors (internal wiring, including wires in a terminal box or compartment) that operate at different voltages shall comply with at least one of the following:

- 1) be segregated by internal barriers;
- 2) be segregated from each other;
- 3) be segregated by grounded shielding;
- 4) have all conductors insulated for the highest voltage;
- 5) have either conductor (or the group of conductors for that voltage) insulated for twice the highest voltage.

Insulated conductors shall be separated by internal barriers or shall be segregated from bare live parts at a voltage higher than that for which the conductors are insulated.

Segregation or separation of insulated conductors may be accomplished by clamping, routing or an equivalent means that ensures permanent separation.

If an internal barrier is used to provide separation between the wiring of different circuits, it shall be of adequate mechanical strength and reliably held in place. Barriers shall be firmly secured in place and have sufficient stability and durability to maintain the appropriate separation from live parts under normal service conditions, taking account of relevant external influences (see IEC 61439-1).

Barriers of insulating material shall have appropriate thickness, if of electrical grade paper and, when located between conductors and bare live parts of different circuits, shall comply with 4.6.2.3.

4.7.12 Protection of receptacles

An output receptacle shall be protected by an overcurrent device rated or set at not more than the rating of the receptacle unless:

- 1) the circuit is not capable of delivering current in excess of the rating of the receptacle under any conditions of loading; or
- 2) electronic protection is provided that cannot be defeated by a single fault.

4.7.13 Earthing and bonding

4.7.13.1 General requirements for earthing and bonding

Where applicable, the connection between the earthing terminal or earthing contact and earthed metal parts shall have low resistance. Compliance is demonstrated in 7.14.

4.7.13.2 Portable stand-alone fuel cell power systems

The frame of a portable stand-alone fuel cell power system shall not be required to be grounded and shall be permitted to serve as the earthing electrode under the following conditions:

- 1) the generator supplies only equipment mounted on the portable stand-alone fuel cell power system, cord-and-plug-connected equipment through receptacles mounted on the portable stand-alone fuel cell power system, or both;
- 2) the non-current-carrying metal parts of the equipment and the equipment earthing conductor terminals of the receptacles are bonded to the portable stand-alone fuel cell power system frame.

4.7.13.3 Uninterruptible power systems (UPS)

Uninterruptible power systems (UPS) shall meet the earthing and grounding provisions of IEC 62040-1 and IEC 62040-2 as applicable.

Accessible conductive parts of Class I equipment, which might assume a hazardous voltage in the event of a single insulation fault, shall be reliably connected to a protecting earthing terminal within the equipment.

4.8 Protection against fire hazard

4.8.1 General intent and purpose of protection against fire hazard

Subclause 4.8 specifies requirements intended to reduce the risk of ignition and the spread of flame, both within the equipment and to the outside, by the appropriate use of materials and components and by suitable construction.

4.8.2 Flammability

Components and materials inside the portable fuel cell power system enclosure shall be so constructed or shall make use of such materials, that propagation of fire and ignition is minimized. This may be demonstrated through the appropriate selection of materials meeting FV 0, FV 1 or FV 2 when tested in accordance with IEC 60695-11-10 or IEC 60695-11-20.

Exemptions:

- Membranes, or other materials within a single portable fuel cell power system or stack which comprise less than 10 % of its total mass, are considered to be of limited quantity and are permissible without flammability ratings.

- Components shall be protected against overheating under fault conditions. Where it is not practical to protect components against overheating under fault conditions, the components shall be mounted on materials of flammability Class V-1 or better. Additionally, such components shall be separated from material of a class lower than flammability Class V-1 by at least 13 mm of air, or by a solid barrier of material of flammability Class V-1.

Parts of insulating material supporting current-carrying connections, and parts of insulating material within a distance of 3 mm of such connections, are subjected to the glow-wire test of IEC 60695-2-11. However, the glow-wire test is not carried out on parts of material classified as having a glow-wire ignition temperature, according to IEC 60695-2-13, of at least

- a) 775 °C, for connections which carry a current exceeding 0,2 A during normal operation,
- b) 675 °C, for other connections, provided that the test sample was no thicker than the relevant part.

When the glow-wire test of IEC 60695-2-11 is carried out, the temperatures are

- 1) 750 °C, for connections which carry a current exceeding 0,2 A during normal operation,
- 2) 650 °C, for other connections.

Parts that withstand the glow-wire test of IEC 60695-2-11, but which, during the test, produce a flame that persists for longer than 2 s, are further tested as follows.

Parts above the connection within the envelope of a vertical cylinder having a diameter of 20 mm and a height of 50 mm are subjected to the needle-flame test of IEC 60695-11-5. However, parts shielded by a barrier that meets the needle-flame test of IEC 60695-11-5 are not tested. The needle-flame test is not carried out on parts of material classified as V-0 or V-1 according to IEC 60695-11-10, provided that the test sample is no thicker than the relevant part.

4.8.3 Openings in equipment

The risk of ignition caused by small metallic objects, such as paper clips or staples, shall be reduced by measures to minimize the likelihood of such objects entering the equipment and bridging bare conductive parts between which the voltage is not limited in accordance with 4.6.4.

Acceptable measures include:

- a) providing openings that do not exceed 1 mm in width regardless of length;
- b) providing a screen having a mesh with nominal openings not greater than 2 mm between centre lines and constructed with a thread or wire diameter of not less than 0,45 mm;
- c) providing internal barriers.

Additionally, where metallized parts of a barrier or enclosure are within 13 mm of parts of circuits where the available power is greater than 15 VA, one of the following requirements applies:

- 1) access by a foreign metallic object shall be limited in accordance with the above acceptable measures even though the available voltage meets the limits of 4.6.4;
- 2) there shall be a barrier between the bare conductive parts and the enclosure;
- 3) fault testing shall be carried out to simulate bridging along a direct path between a bare conductive part and the nearest metallized part of a barrier or enclosure that is within 13 mm of the bare conductive part.

Examples of metallized plastic barriers or enclosures include those made of conductive composite materials or that are electroplated, vacuum-deposited, painted or foil lined. Compliance is checked by inspection and measurement and, where appropriate, by test. If simulated fault testing is carried out, no ignition of the metallized barrier or enclosure should occur.

Openings in the vertical sides of an enclosure of a portable fuel cell power system shall not allow intrusion of objects or material that would cause injury to persons or malfunction of equipment that would result in a shock or release of energy that meets or exceeds a hazardous energy level.

Portable fuel cell power systems with openings at the bottom of the enclosure shall comply with the applicable requirements of IEC 60950-1:2005, 4.6.2.

4.9 Protection against temperature hazards

4.9.1 General requirements for protection against temperature hazards

Components working at high temperature shall be effectively shielded or separated to avoid overheating of their adjacent materials and components.

4.9.2 Surface temperatures

The maximum temperature of any surface(s) that may be contacted by personnel performing regular and routine service while the portable fuel cell power system is in operation shall not exceed the limit(s) given in IEC 60335-1:2010 and IEC 60335-1:2010/AMD1:2013, Clause 11.

Compliance is checked by determining the temperature rise of the various parts under the conditions specified in 7.5.

4.9.3 Component temperatures

The maximum temperature of any component shall not exceed the limit(s) given in IEC 60335-1:2010 and IEC 60335-1:2010/AMD1:2013, Clause 11.

Compliance is checked by determining the temperature rise of the various parts under the conditions specified in 7.6.

4.9.4 Wall, floor and ceiling temperatures

The temperatures on walls, floor and ceiling adjacent to a portable fuel cell power system shall not exceed 50 °C above ambient temperature under the test conditions of 7.7.

4.10 Protection against electromagnetic disturbances

The portable fuel cell power system shall have an adequate level of immunity to electromagnetic disturbances so that it can operate correctly in its intended environment. In addition, the equipment shall not generate electromagnetic disturbances above the levels appropriate for its intended places of use.

As applicable, the portable fuel cell power system shall comply with IEC 61000-6-1 and IEC 61000-6-3 for residential, commercial and light industrial environments. If the portable fuel cell power system is intended to be used in industrial environments, the following standards shall be referenced: IEC 61000-6-2; IEC 61000-6-4; IEC 61000-3-2 and IEC 61000-3-3, as applicable.

4.11 Hazard and risk assessment

4.11.1 General requirements for hazard and risk assessment and the approach

The manufacturer shall ensure that:

- a) all foreseeable hazards, hazardous situations and events associated with the portable fuel cell power system throughout their anticipated lifetime have been identified;

- 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 in accordance with IEC 61882, IEC 61511-3 or equivalent methodology;
- c) the two factors which determine each one of the estimated risks (probability and severity) have been eliminated or reduced as far as possible through design (inherently safe design and construction);
- d) the necessary protection measures in relation to risks that are not eliminated have been taken (provision of warning and safety devices);
- e) users are informed of any additional safety measures that they may be required to implement.

4.11.2 Safety and reliability analysis

The manufacturer shall demonstrate that the necessary protection measures in relation to risks that are not eliminated have been taken by performing a safety and reliability analysis which is intended to identify failures that have significant consequences affecting the system performance and/or safety.

The safety and reliability analysis shall be performed in accordance with IEC 60812, IEC 61025 or equivalent.

4.12 Safety control circuits

Automatic electrical and electronic controls shall be designed and constructed so that they are safe and reliable in conformance to IEC 60730-1, IEC 61508-1 or IEC 61511-1, as appropriate.

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

Protective devices, such as relays, switches and transformers, that meet the requirements of the relevant product standards shall be exempt from this component failure analysis. For example, automatic electrical burner control systems shall comply with IEC 60730-2-5.

The design of a safety-control circuit shall be such that electrical failure of an individual functional part will either

- 1) interrupt the intended function under its control, or
- 2) allow completion of an operational cycle, but will fail to start again or will lock out on the subsequent cycle.

4.13 Protection against oxygen depletion

Portable fuel cell power systems shall avoid the oxygen depletion below a concentration of 18 vol % to ensure compliance with health and safety limits for the user.

The manufacturer of the portable fuel cell power system shall implement technical measures and/or define safe modes of operation for the user to avoid oxygen depletion.

Secure methods of operation can be indicated on a warning label/display and can also refer to dedicated areas in the user manual. Operational methods/warnings include messages such as:

- Limitation/definition of room volume and/or indoor operation duration
- Provide sufficient air supply when operated indoors
- For outdoor use only

Detailed instructions in the operational manual shall be referred to in the warning message.

Portable fuel cell power systems that are intended to use indoors shall comply with 7.21.

Compliance with 7.21 is not required for portable fuel cell power systems that are intended to be used outdoors only.

4.14 Emission of effluents

Emissions of effluents need to be limited in order to protect the users from hazards and to comply with regional or national air quality and emission standards. Hazards could result from excessive concentration of harmful or toxic effluents in the ambient air, especially but not exclusively from systems dedicated for indoor or outdoor use.

The manufacturer of the portable fuel cell power system shall implement technical measures and/or define safe modes of operation for the user to avoid excessive concentration of emission of restricted effluents. Concentration limits for various potential effluents based on the short-term exposure limit (STEL) are given in Table 1.

Secure methods of operation can be indicated on a warning label/display and can also refer to dedicated areas in the user manual. Operational methods/warnings include messages such as:

- Limitation/definition of room volume and/or indoor operation duration
- Provide sufficient air supply when operated indoors
- For outdoor use only

Detailed instructions in the operational manual shall be referred to in the warning message.

Portable fuel cell power systems that are intended to be used indoors – that are not marked with **“FOR OUTDOOR USE ONLY”** – shall comply with 7.22.2 and 7.22.3.

Portable fuel cell power systems that are intended to be used outdoors and that are marked **“FOR OUTDOOR USE ONLY”** shall comply with 7.22.2 at the exhaust. No other emission testing is required for portable fuel cell power systems that are intended to be used outdoors and are marked **“FOR OUTDOOR USE ONLY”**.

4.15 Fuel supply

Where necessary, means shall be provided to allow for a ground connection during refueling. The replenishment port on non-standard fuel tanks shall be incompatible with standard fuel storage connections.

Fuel storage systems using hydrogen stored in metal hydrides shall comply with ISO 16111.

Where the fuel supply is resident within the portable fuel cell power system, in either an integral, or removable and refillable container assembly (pressurized or non-pressurized), the fuel container shall meet applicable national regulatory requirements.

Means shall be provided to secure fuel containers from becoming dislodged while in use or stored on the portable fuel cell power system. Lateral movement shall not exceed an amount that results in a hazardous condition. Compliance is checked by 7.27. Any integral compressed gas fuel container shall include a connection fixture that will not allow the flow of gas until a positive gas seal has been achieved. The fuel connection device connecting the fuel supply and the system shall be suitable for its application.

4.16 Fuel processing systems (if applicable)

Fuel processing systems and fuel processing components shall be able to withstand stress due to shock, vibration and temperatures anticipated during normal usage. See Annex B for guidance.

4.17 Enclosures

4.17.1 General requirements for all enclosures

Enclosures for electrical equipment shall be formed and assembled so that they will have the strength and rigidity necessary to resist the abuse to which they may be subjected, without increasing their fire and accident hazards due to partial collapse and without reduction of spacing, loosening or displacement of parts or other serious defects.

For applications where the equipment may be exposed to moisture, dust, or other injurious materials in normal operation, the protection afforded to the enclosed components shall be compliant with the applicable ingress protection “IP” rating in accordance with IEC 60529.

Enclosures shall be sufficiently complete to contain or deflect parts that, because of failure or for other reasons, might become loose, separated or thrown from a moving part.

4.17.2 Enclosure requirements for outdoor use

The enclosure shall have a degree of protection at least IPX4D according to IEC 60529.

4.18 Battery supplies

4.18.1 General requirements for batteries

A battery shall be so located and mounted that the terminals of cells will be prevented from coming in contact with the terminals of adjacent cells, or with the metal parts of the battery compartment, as a result of shifting of the battery.

If transformer isolation is not provided between the AC input circuit of the portable fuel cell power system and the battery circuit, the battery terminals shall be guarded to reduce the likelihood of unintentional contact with the battery terminals.

A battery that requires the addition of water shall have a means to determine the fluid level. Batteries shall be protected from overcharging, reverse charging and rapid discharging in accordance with IEC 60950-1:2005, 4.3.8.

Primary lithium batteries shall comply with IEC 60086-4. Secondary lithium batteries shall comply with IEC 62133 (all parts).

4.18.2 Battery compartments

Battery compartments shall be suitable for the service and resistant to potential leakage.

A polymeric enclosure or compartment housing a wet cell battery, such as a lead-acid storage battery, shall be resistant to corrosion by acids or alkalis, as applicable.

The enclosure or compartment housing a wet cell battery, such as a lead-acid storage battery, shall be constructed so that spillage or leakage of the electrolyte from the volume of one battery container will be contained within the enclosure and prevented from

- 1) reaching the outer surfaces of the portable fuel cell power system where contact with the user is possible,
- 2) contaminating adjacent electrical components or materials,
- 3) bridging required electrical spacing.

A metal case or container of a battery, such as an alkaline battery, shall be insulated or spaced away so as not to contact uninsulated live parts of the portable fuel cell power system if such contact may result in a short-circuit.

An enclosure or compartment housing batteries having metal containers or cases that are conductively connected to a battery electrode shall be such that the batteries are insulated or spaced from each other, or otherwise physically arranged, to prevent short-circuiting of part or all of the battery supply after installation in the portable fuel cell power system.

4.18.3 Vented wet cell batteries

Vented wet cell batteries may be integral with the portable fuel cell power system, provided all of the following conditions are met:

- a) the enclosure or compartment housing the batteries is vented;
- b) arcing parts such as the contacts of switches, circuit-breakers and relays are not located in the battery compartment;
- c) the battery compartment does not vent into compartments with enclosed spaces that contain arcing parts;
- d) where a hazard may be present through system orientation or positioning, instructions shall be provided and the portable fuel cell power system shall be marked.

NOTE The requirements of 4.18.3 do not apply to sealed cell or valve regulated batteries.

4.18.4 Ventilation of battery compartments

If vented wet cell batteries are housed in an enclosure or compartment, the minimum ventilation rates shall comply with the requirements of Annex A.

4.19 Pressure vessels and piping

4.19.1 General requirements for pressure vessels and piping

The design and construction of both rigid and flexible components carrying fluids under high pressure, and fittings, shall be designed, constructed and tested in accordance with the appropriate national requirements as outlined in ISO 16528 (all parts).

Fuel storage systems using hydrogen stored in metal hydrides shall comply with ISO 16111.

Where piping systems are designed for internal pressures over 100 kPa, they shall be designed, constructed, and tested in accordance with ISO 15649.

Piping designed for operation below 100 kPa, or piping that the applicable regional or national pressure equipment codes and standards do not consider to be pressure piping (such as low-pressure water hoses, plastic tubing or other connections to atmospheric or low-pressure tanks and similar containers) shall be constructed of suitable materials and fittings, and designed and constructed with adequate strength and leakage resistance to prevent unintended releases.

For materials (piping, accessories, joints or vessels) that will be in direct contact with hydrogen, refer to ISO 16110-1:2007, Annex B, as a source of information to prevent problems of incompatibility.

4.19.2 Piping systems

All piping materials, thread compounds and thread tapes shall not be degraded through interaction with the system constituents. Unions, when used in gas lines, shall be appropriately constructed and if a packing is used it shall be resistant to the action of the gases.

For liquid fuel piping, a filter shall be provided upstream of the fuel controls.

Special consideration shall be given to the following aspects:

- a) overstressing from inadmissible free movement or excessive stresses and strains being produced, for example, on flanges, connections, bellows or hoses; overstressing can be avoided by means such as support, constraint, anchoring, alignment and pre-tension;
- b) rupture events (sudden movement, high-pressure jets, etc.);
- c) condensation during start-up and/or use occurring inside enclosures for gaseous fluids which could cause damage from water hammer, vacuum collapse, corrosion and uncontrolled chemical reactions; in such a case means shall be provided for drainage and removal of deposits from low areas and for access during cleaning, inspection and maintenance;
- d) 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;
- e) the piping for explosive, flammable or toxic fluids shall be suitable for their purpose.

4.20 Hoses

Hoses used for liquid fuels shall be suitable for the application. Compatibility includes absence of corrosion of the hose material and no breakdown of physical properties in use.

Hoses used for liquid fuels shall be used within their maximum allowable working pressures and temperatures for all conditions of normal, abnormal, emergency and faulted operating and shutdown conditions of the portable fuel cell power system.

4.21 Automatic shut-off valves

Flammable gas supplied to the portable fuel cell power systems shall pass through at least two automatic shut-off valves, in series, each of which serves as an operating valve and a safety shut-off valve. Additionally:

- a) electrically-operated safety shut-off valves shall be of a type that will close upon current failure;
- b) the valve closing time of safety shut-off valves shall not exceed 1 s;
- c) automatic valves shall comply with IEC 60730-2-17;
- d) placement of the two valves can be either in the fuel line feeding the fuel power system or, for a fuel cell power system relaying on water reactive technology, one valve placed in the water reactant line and the other valve placed in the fuel line.

4.22 Regulators

The gas pressure regulator shall be equipped with a vent limiter or a vent line.

4.23 Process control equipment

Process control equipment and monitoring devices, such as sensors, indicators and transmitters, shall comply with the applicable parts of the IEC 60079 series such as IEC 60079-29 (all parts), and the applicable parts of the IEC 60730 series such as IEC 60730-1 or other nationally recognized standards as appropriate for the application.

4.24 Filters

4.24.1 Air filters

Air filters shall be of a type suitable for the application and shall be reasonably accessible for inspection and replacement. The air velocity through a filter shall not exceed the filter manufacturer's recommended air velocity.

4.24.2 Liquid fuel filters

Liquid fuel filters shall be designed by the manufacturer as a pressure part, suitable for the maximum working pressure of the adjacent fuel system.

Liquid fuel filters and their filter media shall be compatible with the fuel used.

4.25 Motors

Electric motors shall be designed for continuous duty and shall be provided with overload protection in accordance with the applicable clauses/subclauses of the relevant parts of the IEC 60034 series.

4.26 Fuel pumps

Fuel pumps shall be designed for the specific fuel and for the pressures and temperatures to which it may be subjected under normal operating conditions. Fuel pumps shall be provided with the following:

- a) pressure relief devices that limit both inlet and outlet piping pressure to less than the design pressure of the piping; if the shut-off head is less than the pressure rating of the piping, relief valves are not required; relief valve discharge shall be recycled to the fuel tank or routed to a safe place;
- b) an automatic shutdown on high discharge pressure;
- c) suction and discharge lines shall be adequately protected from damage due to vibration;
- d) shaft seals compatible with the fluids, temperatures and pressures expected in normal and abnormal operation and during normal and emergency shutdowns;
- e) motors, bearings and seals suitable for the expected duty cycles.

5 Instructions

5.1 Operation and maintenance manual

Instructions to be referred to as the operation and maintenance manual shall be provided with the portable fuel cell power system. Instructions related to product safety shall be provided in printed form. This manual shall contain clearly defined, legible and complete instructions for at least the following:

- a) directions that the area surrounding the portable fuel cell power system shall be kept clear and free of combustible materials, gasoline and other flammable vapours and liquids;
- b) where requiring air for combustion or ventilation, instructions to provide adequate ventilation either from outside air or adjacent spaces, not to block or obstruct air openings on the portable fuel cell power system, air openings communicating with the area in which the portable fuel cell power system is installed, and the required spacings around the portable fuel cell power system that provide clearances to secure and discharge required air;
- c) instructions for electrical connections (grounding, if applicable) and starting and shutting down the portable fuel cell power system; these instructions shall illustrate and locate all components;
- d) the following statement: "Do not use this portable fuel cell power system if any part has been immersed or flooded with water. Immediately call the manufacturer or manufacturer's representative to inspect the portable fuel cell power system and to replace any functional part that has been affected";
- e) specifications for the frequency of filter change or cleaning and the dimensional size and type of filter for replacements; these instructions shall contain directions for removal and replacement of filters and pictorially illustrate and locate all components supplied by the manufacturer referred to in the instructions for removal and replacement of filters;
- f) recommended methods for periodic cleaning of necessary parts;

- g) when a means to neutralize condensate is provided, instructions and a schedule for maintenance, if required;
- h) instructions for lubrication of moving parts, including type, grade and amount of lubricant;
- i) instructions for examining the portable fuel cell power system installation to determine that
 - 1) any intake or exhaust openings are clear and free of obstructions,
 - 2) there are no obvious signs of deterioration of the portable fuel cell power system;
- j) a list of replacement parts and the source where such parts are available;
- k) the necessity and minimum frequency for examinations and periodic inspection of the portable fuel cell power system by the user and by qualified service personnel, if required;
- l) where a hazard may be present through system orientation or positioning, instructions shall be provided and the portable fuel cell power system shall be so marked;
- m) documentation of all hazardous chemicals contained within the portable fuel cell power system with a description of the hazard and instructions for remedial action should the user or service personnel be contaminated;
- n) an enumeration of all regular and routine maintenance items to be performed on the equipment;
- o) manufacturer's or distributor's name, address, and telephone number;
- p) the following statement for portable fuel cell power systems intended only for indoor use:

CAUTION: FOR INDOOR USE ONLY

- q) the following statement for portable fuel cell power systems intended only for outdoor use:

**WARNING: FOR OUTDOOR USE ONLY. RISK OF ASPHYXIATION
OR CARBON MONOXIDE POISONING. DO NOT OPERATE INDOORS**

- r) the following statement for portable fuel cell power systems intended for indoor use and equipped with the operational mode, including automatic shutdown after a predetermined time:

WARNING: DO NOT RESTART BEFORE SUFFICIENT VENTILATION

- s) proper earthing connections, if applicable;
- t) the composition limits and supply characteristics of the fuels to be used in the fuel cell power system;
- u) proper refuelling and if applicable, disposal of depleted fuel containers;
- v) periodic inspection of refuelling connections;
- w) the altitude above sea level up to which the fuel cell power system shall be capable of operating correctly;
- x) the range of air temperatures within which the fuel cell power system shall be capable of operating correctly;
- y) the range of temperatures within which the fuel cell power system shall be stored;
- z) for outdoor portable fuel cell power systems, the considered environment for the design of the fuel cell power system where it may be used including wind speed, rain intensity and direction, airborne particles, airborne dust (protective index), and air quality (pollution component);
- aa) the acceptable tilt limits for its use;
- bb) if specific instructions are necessary to avoid the risk of explosion, they shall be included in the operation and maintenance manual.

5.2 User's information manual

5.2.1 User's information manual general requirements

A user's information manual shall be provided for a portable fuel cell power system. The manual shall be provided in the official language of the countries of expected use.

The user's information manuals shall be formatted to provide easy-to-follow procedures. Instructions related to product safety and operational/environmental conditions shall be provided in printed form. Illustrations should be used to identify portable fuel cell power system components, dimensions and clearances, assembled component, and connection points as needed to make the instructions clear. Illustrations should also be used to identify the location of user serviceable components and illustrate correct methods for performing service procedures.

When text is shown in quotation marks, it shall appear in the user's information manual exactly as shown.

Each user's information manual should be divided into appropriate chapters or sections, and should include a table of contents and clearly marked page numbers.

The user's information manual shall contain the safety information given below.

5.2.2 User's information manual front cover

The front cover shall present the user(s) with only the most important safety instructions. The front cover or, in the absence of a cover, the first page of the manual shall bear the applicable safety labelling in accordance with ISO 7010.

The boxed warning shall contain the following additional statement when the portable fuel cell power system is intended only for indoor use:

FOR INDOOR USE ONLY

The boxed warning shall contain the following additional statement when the portable fuel cell power system is intended only for outdoor use:

**WARNING: FOR OUTDOOR USE ONLY. RISK OF ASPHYXIATION
OR CARBON MONOXIDE POISONING. DO NOT OPERATE INDOORS**

The boxed warning shall contain the following statement for portable fuel cell power systems intended for indoor use and equipped with the operational mode, including automatic shutdown after a predetermined time:

WARNING: DO NOT RESTART BEFORE SUFFICIENT VENTILATION

The front cover shall include a statement informing users that they need to read all instructions in the manual, and shall keep all manuals for future reference.

5.2.3 Users information manual safety section

A safety section shall be included near the front of the manual to provide portable fuel cell power system users with a listing of potential hazards and safety-related instructions for a particular portable fuel cell power system. Statements along the following lines shall be included in the safety section with references to specific clauses or pages of the manual for more information:

- a) directions that the area surrounding the portable fuel cell power system needs to be kept clean and free of gasoline and other flammable vapours and liquids;