BS IEC 60860:2014

BSI Standards Publication

Radiation protection instrumentation — Warning equipment for criticality accidents

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National foreword

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Radiation protection instrumentation – Warning equipment for criticality accidents

Instrumentation pour la radioprotection – Equipement de signalisation des accidents de criticité

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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RADIATION PROTECTION INSTRUMENTATION – WARNING EQUIPMENT FOR CRITICALITY ACCIDENTS

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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International Standard IEC 60860 has been prepared by subcommittee 45B: Radiation protection instrumentation, of IEC technical committee 45: Nuclear instrumentation.

This second edition cancels and replaces the first edition issued in 1987. It constitutes a technical revision.

The main technical changes with regard to the previous edition are as follows:

– reference to IEC 61508 concerning the safety classification;
– introducing requirement for the alarm sound level (90 dBA and 115 dBA at a distance of 1 m from the alarm source);
– energy response requirement changes from (–35 %, +35 %) to (–35 %, +50 %);
– time period of 1 min is specified for the overload requirement (1 kGy·h^{-1} during a period of at least 1 min);
– updated EMC, mechanical and environmental requirements according to IEC 62706.

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

FDIS	Report on voting
45B/791/FDIS	45B/794/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.

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.

RADIATION PROTECTION INSTRUMENTATION – WARNING EQUIPMENT FOR CRITICALITY ACCIDENTS

1 Scope and object

This International Standard applies to equipment intended to provide warning of a criticality accident by the detection of gamma radiation, neutrons or both from such an event.

This standard is primarily intended to apply to equipment design and, therefore, does not address the need for placement of such equipment. The need for criticality alarm systems and the utilisation procedures are described in ISO 7753 and ISO 11320.

The primary purpose of the criticality alarm system is to detect radiation from criticality accidents and warn personnel. Suitable alarms shall be provided so that personnel present in the area involved and in adjacent effected areas (often the complete facility) can be warned in the event of a criticality accident occurring. These alarms are intended to activate an evacuation alarm to reduce the probability of serious exposure to personnel.

Such systems may also have secondary functions, such as providing a follow-up measurement of the radiation level during the accident. The systems should only be used for these secondary functions, provided that the secondary functions have no adverse effect on the criticality alarms and their essential characteristics (for example, reliability) described in this standard.

The object of this standard is to prescribe general, radiation detection, environmental, mechanical, electromagnetic and documentation requirements and to specify acceptance criteria for criticality accident warning equipment.

This standard is not applicable to photon or neutron dose equivalent (rate) meters or monitors covered by IEC 60532, IEC 60846 (all parts), IEC 61017 (all parts), and IEC 61005. This standard is not applicable either to equipment or assemblies used in control and safety systems of nuclear reactors.

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 60050 (all parts): *International Electrotechnical Vocabulary* (available at http://www.electropedia.org)

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

IEC 62706, *Radiation protection instrumentation – Environmental, electromagnetic and mechanical performance requirements*

ISO 7753:1987, *Nuclear energy – Performance and testing requirements for criticality detection and alarm systems*

International Bureau of Weights and Measures: *The International System of Units, 8th edition, 2006*

3 Terms and definitions, quantities and units

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in IEC 60050-395 apply.

3.1.1
acceptance test
contractual test to prove to the customer that the device fulfils certain specifications

3.1.2
alarm
method for notification of a criticality accident

3.1.3
alarm set point
minimum radiation dose and/or dose rate that will activate the alarm

3.1.4
conventional quantity value (dose)
quantity value attributed by agreement to a quantity for a given purpose

Note 1 to entry: The term "conventional true quantity value" is sometimes used for this concept, but its use is discouraged.

Note 2 to entry: Sometimes a conventional quantity value is an estimate of a true quantity value.

Note 3 to entry: A conventional quantity value is generally accepted as being associated with a suitably small measurement uncertainty, which might be zero.

Note 4 to entry: In this standard the quantity is the dose.

[SOURCE: VIM:2007, 2.12]

3.1.5
criticality accident
release of energy as a result of an accidentally produced self-sustained or divergent neutron chain reaction

3.1.6
criticality alarm system
all parts of the assembly, subassemblies, functional units and components that together make a workable system, including all circuitry, alarms, connections, cables, detectors, and auxiliary subassemblies. The criticality alarm system comprises at least the following subassemblies:

– detection subassembly, including associated electronics;
– warning subassembly including the logic unit and alarm unit

3.1.7
false alarm
activation of the alarm signal in the absence of a criticality accident

3.1.8
type test
conformity test made on one or more items representative of the production

3.2 Quantities and units

In the present standard, units of the International System (SI) are used[1]. The definitions of radiation quantities are given in IEC 60050-395. The corresponding old units (non-SI) are indicated in brackets.

Nevertheless, the following units may also be used:

– for energy: electron-volt (symbol: eV), 1 eV = $1{,}602 \times 10^{-19}$ J;
– for time: hour (symbol: h) or minute (symbol: min).

4 General requirements

4.1 General characteristics

Criticality alarm systems are designed for the automatic and prompt detection of gamma radiation or neutrons from a criticality accident and to actuate immediate evacuation and warning alarms. The primary functions of the criticality alarm system shall be to:

– detect a criticality accident as soon as it occurs within the monitoring zone of the detector(s);
– actuate an alarm with minimal delay;
– achieve a high degree of reliability required by its safety classification and low probability of false alarm;
– fail safe by design and reveal failures (single failure shall be indicated but shall not disable the system and result in a potential non-detection of a criticality accident);
– be secured against unauthorised adjustment.

Secondary functions of the criticality alarm system should be established by agreement between the manufacturer and user. A recommended secondary function should include the ability to measure radiation levels during and following a criticality accident.

It shall be possible to test the response and performance of the criticality alarm system without causing personnel evacuation.

4.2 Detection criterion

The following detection criterion definition described in ISO 7753 is used. Criticality alarm systems shall be designed to detect promptly the minimum accident of concern. For this purpose, in typical unshielded process areas, the minimum accident may be assumed to deliver an equivalent absorbed neutron and gamma dose in free air of 0,2 Gy at a distance of 2 m from the reacting material within 60 s. Very slowly increasing excursions, while unlikely to occur, may not attain this value. Furthermore, excursions in unmoderated systems will probably occur much more rapidly.

In the design of radiation detectors, it may be assumed that the minimum duration of the radiation transient is 1 ms FWHM (Full Width Half Maximum). The criticality alarm system shall be designed so that instrument response and latched alarm occur as a result of transients of such duration.

4.3 Safety classification

The equipment covered in this standard may be installed in facilities such as nuclear fuel storages and processing sites.

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1 International Bureau of Weights and Measures: The International System of Units, 8th edition, 2006.

The basic safety standard IEC 61508 applies. The SIL (Safety Integrity Level) specification for equipment shall be SIL1 as a minimum. The requirement for higher SIL specification (SIL2-4) shall be agreed between manufacturer and purchaser. Compliance with IEC 61513 will facilitate consistency with the requirements of IEC 61508 as they have been interpreted for the nuclear industry.

4.4 False alarms

Particular consideration shall be given, during the design of the criticality alarm system, to minimize false alarms.

A redundant system, requiring response from at least two detector channels out of three (2OO3) is one of the methods used in minimising false alarms. If a redundant system is used, alarm or failure of any single channel shall not activate the alarm or render the criticality alarm system inoperative. A warning signal of a detected malfunction shall be provided in this case and the system shall continue to operate as a one out of two (1OO2) redundant system using the remaining healthy channels.

The maintenance requirements shall be kept to the minimum practicable and the equipment shall be designed to facilitate maintenance without causing false alarms.

4.5 Failure of components

For all criticality alarm systems, it is recommended that a failure modes and effects analysis (FMEA) in accordance with IEC 60812 is carried out to identify any potential failure modes, their causes and the effects on system performance. This will assist in the development of the design, and identify areas requiring modification or design improvement for mitigation against failure modes.

Failure of components which would directly affect the detection and warning capability of the criticality alarm system shall be designed to fail safe and reveal failures by visual and/or audible indication.

A revealed failure shall result in corrective action being immediately taken to return the system to full operational state. To avoid loss of confidence and disruption of work, warnings of instrument failure should be distinguishable, whenever possible, from warnings due to genuine radiological hazards.

4.6 Ease of decontamination

The assemblies shall be designed in such a manner as to facilitate decontamination.

4.7 Multiple function systems

If the system is to be used for secondary functions in addition to criticality accident detection, it shall be designed in such a manner as not to compromise its primary purpose of criticality accident detection and warning.

4.8 Interconnection cables and connectors

4.8.1 Interconnecting cables

The criticality alarm system shall include a device for self-verification to determine complete operability with its installed interconnecting cables. These cables shall be protected from spurious signals which could activate the warning subassembly or render the assembly inoperative.

4.8.2 Connectors

Cable connectors shall be mechanically secured.

4.9 Reliability

All assemblies shall be designed to the standard of reliability defined by the specified SIL (Safety Integrity Level), i.e. the Probability of Failure on Demand (PFD). The manufacturer shall specify the period between proof tests, when operational in the facility which is required to meet the specified SIL(PFD). The manufacturer shall specify the periods between the necessary maintenance operations, and provide full maintenance procedures. The maintenance requirements shall be kept to the minimum practicable.

4.10 Functional testing

It is recommended that individual subassemblies and units are capable of being functionally tested without being removed from the criticality alarm system.

4.11 Interchangeability

It is recommended that all subassemblies and units of similar function such as detectors, readout and display units, and power supplies be of modular construction enabling easy replacement of these items.

4.12 Detection subassembly

A detection subassembly refers to the equipment by which the radiation from a criticality accident is detected, and may consist of more than one radiation detector and auxiliary circuits. A detection subassembly shall:

– have suitable response to gamma radiation, neutrons or both produced by a criticality accident (see Clause 6);
– not be inhibited by gamma and/or neutron overload dose (see overload characteristics, 6.6).

4.13 Logic unit for signal treatment

This unit processes the information originating from the detection assemblies concerning gamma and/or neutron radiation. Failure of any one detector or any one component of the logic unit shall not result in the failure of the criticality alarm system.

A means shall be provided to check the proper functioning of each detector channel at any time without compromising the criticality alarm system or causing an evacuation.

4.14 Alarm signals unit

4.14.1 Alarm signals

Audible alarm signals shall be of distinctive tone, the acceptable level shall be established between the manufacturer and user, and shall give a clear warning above background noise. The sound level shall be between 90 dBA and 115 dBA at a distance of 1 m from the alarm source. The audible and visual alarms shall be continuous until manually reset. Manual activation means may also be provided, but with limited access. Manual reset should be external to the area to be evacuated. Automatic reset after a pre-defined period could be possible if this does not decrease the reliability of the system.

In areas with high background noise or required hearing protection, visual alarm signals or other alarm means should be considered in addition to those stated above.

4.14.2 Alarm set point

The alarm set point of the detection system should be adjustable. The setting controls shall be protected against unauthorized adjustment.

5 General test procedure

5.1 Nature of tests

Unless otherwise specified, all tests enumerated in this standard are to be considered type tests. Certain tests may be considered acceptance tests by agreement between the manufacturer and user.

5.2 Reference conditions and standard test conditions

Reference and standard test conditions are given in Table 1. Reference conditions are those conditions to which the performance of the assembly is referred, whereas standard test conditions indicate the necessary tolerances in practical testing. Except where otherwise specified, the tests in this standard shall be performed under the standard test conditions given in the third column of Table 1.

Table 1 – Reference and standard test conditions

Influence quantities	Reference conditions (unless otherwise indicated by manufacturer)	Standard test conditions (unless otherwise indicated by manufacturer)
Reference radiation sources	^{60}Co and ^{252}Cf	^{60}Co and ^{252}Cf
Warm-up time	To be specified by manufacturer	To be specified by manufacturer
Relative humidity	65 %	55 % to 75 %
Ambient temperature	20 °C	18 °C to 22 °C
Atmospheric pressure	101,3 kPa	86 kPa to 106 kPa
Power supply voltage	Nominal power supply voltage *Un*	Nominal power supply *Un* ± 5 %
Power supply frequency (AC)	Nominal frequency	Nominal frequency –6 % to +10 %.
Power supply waveform (AC)	Sinusoidal	Sinusoidal with total harmonic distortion lower than 5 %
Angle of incidence of radiation	Calibration direction given by manufacturer	Direction given ±10°
Electromagnetic field of external origin	Negligible	Less than 0,5 times the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the value of the induction due to the earth's magnetic field
Orientation of assembly	To be stated by the manufacturer	Stated orientation ±10°
Assembly control devices	Set for normal operation	Set for normal operation
Contamination by radioactive elements	Negligible	Negligible
Background noise level	Less than 60 dBA	Less than 60 dBA

5.3 Point of test

The point of test is the location at which the reference position of the detection subassembly is placed and at which the value of the appropriate quantity (for example, radiation dose equivalent rate) is known. To calibrate the detection subassembly, it shall be placed with its reference position at the point of test. Every effort shall be made to reduce the scatter radiation at the point of test in the absence of the detection subassembly to less than 10 % of the desired dose rate at that point. Where this is not practicable, the appropriate correction shall be applied.

The manufacturer shall mark on (or state for) the detection subassembly the reference position that should correspond to the effective centre of the detector and give the direction for calibration.

5.4 Reference radiation

Reference radiation shall be provided by ^{60}Co and ^{252}Cf sources, unless the manufacturer and user agree upon the use of other sources (e.g., ^{137}Cs). ^{60}Co is preferred for gamma radiation source instead of ^{137}Cs since its energy is closer to the gamma energy radiated during a criticality accident.

6 Radiation detection requirements

6.1 General

The radiation detection requirements of the detector are determined to enable the user to install the criticality alarm system in compliance with the detection criterion in 4.2. Because of the wide variety of radiation detectors used in criticality alarm systems, only the general principles of testing can be given.

6.2 Energy response

6.2.1 General

The energy response of the detectors shall be such that the system will respond to any event of concern by the detection of radiation of a specified type.

6.2.2 Gamma detectors

6.2.2.1 Requirements

The measured dose over the energy range from at least 0,1 MeV to 3 MeV shall be within an interval (–35 %, +50 %) about the conventional dose.

6.2.2.2 Method of test

The energy response of the detector shall be determined using X or gamma reference radiations as given in ISO 4037.

At least three reference radiations shall be used:

– one shall be at, or below, 100 keV,
– one between 100 keV and 1 MeV,
– and one above 1 MeV.

Where appropriate, additional test equipment may be used to determine the response of the detector (for example, picoampmeter for an ionising chamber). Expose the detector subassembly to known dose rates from the radiations used and note the indications provided by the detector. The energy response of the detector shall comply with the above requirements.

6.2.3 Neutron detectors

6.2.3.1 Requirements

Since widely differing types of neutron detectors (scintillators, ionisation chambers, self powered activation detectors in moderators and junction diodes) with different energy response characteristics may be used in criticality alarm systems, it is only possible to give general guidelines on their use.

The response of all neutron detectors shall be determined using the reference radiation (^{252}Cf fission neutrons or other appropriate source). In addition for those detectors to be installed in a moderated neutron radiation field the response of the detectors shall be determined for such fields.

The energy response of the detector may be measured using ISO standard neutron reference radiations (mono energetic radiations produced by an accelerator). The response of the detector to the moderated neutron field may then be assessed using published data on the neutron leakage spectrum for critical assemblies. Alternatively, the detector response may be directly determined by exposure in a moderated neutron field simulated by a critical assembly or reactor of known dose rate.

6.2.3.2 Method of test

The energy response of the detectors shall be determined using a ^{252}Cf neutron radiation source or other appropriate source (accelerator or reactor) with energy close to the energy radiated during a criticality accident. The energy response to other reference neutron radiations should be also determined.

The appropriate neutron energies as well as the criteria for acceptability should be specified upon agreement between manufacturer and user. In this case, expose the detection subassembly to known dose rates and note the indications provided by the detector. The energy response of the detector shall comply with the criteria for acceptability.

6.3 Response time

6.3.1 Requirements

The system shall be designed to produce the criticality alarm signal within 0,3 s after the detection of criticality event.

6.3.2 Method of test

Expose the equipment to an appropriate criticality excursion. The alarm signal shall be produced within 0,3 s.

6.4 Alarm threshold of detection

6.4.1 Requirements

The equipment shall respond to the direct gamma radiation, neutrons, or a combination of these radiations emitted during a criticality accident and shall meet the alarm threshold of detection specified by the purchaser. The alarm threshold of detection shall be such that when the equipment is installed, it will detect the equivalent of an absorbed neutron and gamma dose in free air of 0,2 Gy at a distance of 2 m from the reacting material within 60 s (see 4.2).

6.4.2 Method of test

The alarm threshold of detection, being the minimum dose to trigger the alarm, should be determined using an appropriate pulsed source of the test radiation. Tests should be made with a range of radiation pulses of duration of about 1 ms to 3 s.

6.5 Variation of response with angle of incidence

6.5.1 Requirements

The angular dependent response of the detection subassembly shall be determined.

6.5.2 Method of test

With a reference radiation source having a suitable activity and positioned at a given distance, the detection subassembly shall be rotated in steps of 30° as specified below in a) and b) and the response to the test radiation shall be recorded. The activity and the distance shall be specified by the manufacturer. The distance shall exceed ten times the maximum dimension of the detection subassembly.

a) Detection subassembly rotated around a horizontal axis passing through the subassembly and orthogonal to the axis through the subassembly and the source.
b) Detection subassembly rotated around a vertical axis passing through the subassembly.

Where appropriate, additional test equipment can be used to determine the response of the detector. The results should be presented in the form of a polar chart.

6.6 Overload characteristics

6.6.1 Requirements

For radiation doses or dose rates greater than those required to initiate the alarm, the warning subassembly shall be activated and remain so until reset. After the test the equipment shall function normally. Detection subassembly shall be tested to a dose rate of at least 1 $kGy \cdot h^{-1}$ during a period of at least 1 min.

6.6.2 Method of test

This test shall be performed using a reactor or other appropriate source of radiation. The detection subassembly is exposed to the above dose rate and the alarm signal shall continue until reset. After the test the equipment shall function normally.

7 Environmental requirements

7.1 Temperature tests without source or injected electrical signal

7.1.1 Requirements

No false alarm is allowed during the temperature changes specified in IEC 62706 from –10 °C to 40 °C.

7.1.2 Method of test

The detection equipment shall undergo the temperature tests specified in IEC 62706 for installed instrumentation from –10 °C to 40 °C. No false shall be allowed.

These tests shall be done prior to the radiation tests.

7.2 Environmental test with source or injected electrical signal

7.2.1 Requirements

The alarm set point shall not vary by more than ± 10 % due to the environmental changes specified in IEC 62706 from –10 °C to 40 °C.

7.2.2 Method of test

The detection equipment should undergo the environmental tests specified in IEC 62706 for installed instrumentation from –10 °C to 40 °C. An appropriate source or an electrical injected signal should be used in order to test that the alarm set point at the temperature extremities shall not vary by more than ± 10 % compared to the alarm set point at 22 °C ± 2 °C.

8 Mechanical requirements

The equipment shall undergo the mechanical tests specified in IEC 62706 for installed instrumentation. No false alarm, mechanical damage or loose components shall be allowed.

These tests will be done prior to the radiation tests.

9 Electromagnetic requirements

The equipment shall undergo the electromagnetic tests specified in IEC 62706 for installed instrumentation. No false alarm shall be allowed.

Then, an appropriate source or an injected electric signal shall be used in order to put the equipment in alarm conditions. The audible alarm shall be switched off and only the output signal shall be monitored. Undergo the radio frequency immunity test as specified in IEC 62706 for installed instrumentation and check if there is a substantial decrease of the output signal at some frequency. The equipment shall remain in alarm condition during the whole test.

These tests shall be done prior to the radiation tests.

10 Documentation

The manufacturers shall make available at the request of the user a report on the type tests carried out according to the requirements of this standard.

The following documentation shall accompany each assembly:

– manufacturer's name or registered trade mark;
– type of assembly and serial number;
– date of manufacture;
– radiation detected;
– type of detector;
– system design description including facility interfaces;
– name of independent testing body and date of tests where applicable;
– results of the tests according to this standard carried out by an independent testing body;
– range of alarm set point.

An instruction manual containing at least the following information shall be supplied:

– installation details;
– a statement of the radiation environment in which all assemblies of the system will continue to operate;
– operational details and maintenance procedures.

Table 2 provides a summary of perfomance requirements.

Table 2 – Summary of performance requirements

Parameter	Performance requirement or specification	Relevant clause/sub clause
Safety classification	SIL1 as a minimum.	4.3
Alarm sound level	Between 90 dBA and 115 dBA at a distance of 1 m from the alarm source.	4.14.1
Gamma response	The measured dose over the energy range from 0,1 MeV to 3 MeV shall be within an interval (–35 %, +50 %) about the conventional dose.	6.2.2
Neutron response	The energy response shall be determined using a ^{252}Cf neutron radiation source or other appropriate source (accelerator or reactor) with energy close to the energy radiated.	6.2.3
Response time	Criticality alarm signal within 0,3 s after the detection of criticality event.	6.3
Alarm threshold of detection	Equivalent absorbed neutron and gamma dose in free air of 0,2 Gy at a distance of 2 m from the reacting material within 60 s.	6.4
Variation of response with angle of incidence	The angular dependent response of the detection subassembly shall be determined.	6.5
Overload characteristics	Detection subassembly shall be tested to a dose rate of at least 1 000 $Gy \cdot h^{-1}$ during a period of at least 1 min.	6.6
Environmental requirements	Without source or injected signal: no false alarm for temperature change from –10 °C to 40 °C and other environmental changes according to IEC 62706. With source or injected signal: the alarm set point shall not vary by more than ± 10 % due to the environmental changes specified in IEC 62706 from –10 °C to 40 °C. Current IEC 62706 environmental changes for this standard include: ambient temperature change (modified from –10 °C to 40 °C), relative humidity (93 % at 35 °C), low/high temperature start-up, IP degree of 51.	7
Mechanical requirements	No false alarm, mechanical damage or loose components during undergoing the mechanical tests specified in IEC 62706. Current IEC 62706 mechanical requirements this standard include: vibrations 0,5 g_n from 10 Hz to 150 Hz.	8
Electromagnetic requirements	No false alarm during the EMC tests according to IEC 62706. Using an appropriate source or an injected electric signal to be in alarm condition and undergo the radio frequency immunity test as specified in IEC 62706. The equipment shall remain in alarm. Current IEC 62706 EMC disturbances for this standard include: electrostatic discharge (6 kV in contact or 8 kV in air), radio frequency immunity (exposure to RF fields in the ranges of 80 MHz to 1 000 MHz and 1,4 to 6 GHz at 10 $V \cdot m^{-1}$), radiated emissions, magnetic fields (100 A/m (1,3 gauss)), AC line powered equipment requirements, immunity from conducted RF and surges and ring waves.	9

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IEC 60846-2, *Radiation protection instrumentation – Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation – Part 2: High range beta and photon dose and dose rate portable instruments for emergency radiation protection purposes*

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