Guidance document on standardization for radiation protection dosemeters in different applications.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

The project GuideRadPROS included both the analysis of the most common dosimeters for radiation protection and the requirements for their characteristics, as set out in international and local standards.

This document has been developed as a guidance for manufacturers and developers of dosimetry equipment for radiation protection. The necessary requirements for dosimeters can be found more easily by following the instructions in this document, which depend on the area of application.

All dosemeters were divided into two main groups.

The first group of dosemeters is personal dosemeters, which are designed to measure personal doses accumulated by personnel working with sources of ionizing radiation or exposed to radiation at work. According to the operating principle, individual dosemeters are categorized into active, passive, and hybrid types. Active dosemeters can also be classified as Electronic (EPD) or Direct Reading dosemeters. Hybrid dosemeters includes the features of passive and active dosemeters.

The second group consists of area dosemeters for environmental monitoring and workplace monitoring. In turn, these dosimeters, like personal ones, are divided into active and passive according to the operating principle and into installed and portable (transportable or mobile). The second group of dosimeters also includes a group of dosemeters intended to be used in emergencies.

There are many different standards which are used for characterization and type testing of radiation protection dosimeters, primarily focused on a specific dosimeter type and on a specific dosimeter application. International Electrotechnical Commission (IEC) standards focused on radiation protection dosimeters are maintained and developed by the Technical Committee TC 45, Subcommittee SC 45B “Radiation protection instrumentation”..

These standards are focused on characteristics of radiation protection dosimeters, providing methods of test and requirements on their performance.

It is known that various factors can influence the performance of a dosimeter, often expressed as the effects of influence quantities on the dosimeter response. Influence quantities are the physical quantities which are not the subject of the measurement process but can affect the measurement result. Typically, the influence quantities are categorized in several groups, as radiation-based, environmental, mechanical, electromagnetic influence quantities, etc.

Most used dosimeters in individual monitoring are the passive dosimetry systems (such as thermoluminescent dosemeters (TLD), optically stimulated luminescence dosemeters (OSLD), etc.), for the measurement of personal dose equivalent for whole-body dose ($H_p(10)$), dose for the extremities ($H_p(0.07)$) and the eye-lens ($H_p(3)$). The use of these dosimeters is often regulated by legal requirements and are mandatory for individual monitoring of occupationally exposed personnel. Passive dosimetry systems are often maintained and distributed by individual monitoring services. The performance of these systems is evaluated against the IEC 62387:2020 standard. Active personal dosimeters (APDs) are increasingly used

in addition to passive dosimeters. These dosimeters usually measure the whole-body personal dose equivalent, $H_p(10)$. The properties of APDs are specified according to IEC 61526:2010.

While individual monitoring is not application specific, the situation with area monitoring standards is quite different. IEC 62387:2020 standard provides test methods and requirements for passive dosimetry systems used for area monitoring as well, in terms of ambient dose equivalent ($H^*(10)$) and directional dose equivalent ($H'(\Omega, 0{,}07)$). This standard covers the application of passive dosimetry systems in regular area workplace monitoring as well as area monitoring in the environment. Active dosimeters used for area monitoring for general workplace monitoring are often tested according to IEC 60846-1:2009 standard. Although in the scope of this standard the environmental area monitoring dosimeters are considered, there are no specific requirements for dosimeters to be met.

The following IEC type-testing standards, which define methods of testing radiation protection dosimeters that measure operational dosimetry quantities, have been identified here. The scope of identified standards is presented in Table 1.

- IEC 61526 is related to active personal dosimeters for individual monitoring which measure personal dose equivalent $H_p(10)$ and $H_p(0.07)$. IEC 61526:2010 covers measurement of X- and γ- photons, β- particles and neutrons with dosimeters which have a digital indication of the measured value and are worn on the torso, or extremities and these dosimeters have alarm functionalities (audial and visual). The standard covers regular individual monitoring of professionally exposed workers, not including special requirements for accident or emergency dosimetry, and does not cover applications in pulsed radiation fields. The last version of this standard, IEC 61526:2024 has been released. The main changes in the new edition cover the inclusion of hybrid dosimeters, measurement of $H_p(0.07)$ and $H_p(3)$, and software requirements for dosimeters. Linearity requirements were harmonized with the ones defined in IEC 62387:2020.
- The standard IEC 62387:2020 covers methods of test and criteria of acceptability for passive dosimetry systems which have integrating passive detectors and are used for individual and area monitoring of photon and beta radiation. A distinction between workplace and environmental area monitoring applications is being made in this standard. Dosimeters covered by this standard are the passive dosimetry systems (TLDs, OSLDs etc.) and hybrid dosimeters. In this standard, requirements for dosimeters in terms of response to different influence quantities, and requirements for the design and software data and interfaces of passive dosimetry systems are defined.
- Five different standards which are related to the dosimeters that measure ambient dose equivalent, $H^*(10)$, have been identified. These standards cover different applications and area monitoring situations including the regular workplace conditions (IEC 60846-1:2009), environmental monitoring

(IEC 61017:2016), emergency situations (IEC 60846-2:2015), warning assemblies at nuclear facilities (IEC 60532:2010) and IEC 62327:2017. The IEC 62327:2017 is specifically related to the hand-held instruments which can be used for $H^*(10)$ measurements and identification of radionuclides (radiation detection and radionuclide identifiers, Radionuclide Identifying Devices (RIDs)).

Table 1. Scope overview of identified type-testing standards for radiation protection dosimeters.

International standard	Photon energy range, E	Dose (rate) range	Dosimeter	Application	Type of radiation
IEC 61526:2024	80 keV – 1.25 MeV, $H_p(10)$ 20 keV – 150 keV, $H_p(10)$ 30 keV – 250 keV, $H_p(3)$ 30 keV – 1.25 MeV, $H_p(0,07)$ 20 keV –150 keV, $H_p(0,07)$	1 µSv – 1 Sv, $H_p(10)$ 300 µSv – 1 Sv, $H_p(3)$ 1 mSv – 3 Sv, $H_p(0,07)$ (0,5 µSv·h^{-1} - 1 Sv·h^{-1}), $H_p(10)$ (0,1 µSv·h^{-1} - 1 Sv·h^{-1}), $H_p(3)$ (5 µSv·h^{-1} - 1 Sv·h^{-1}), $H_p(0,07)$	active hybrid	personal medical	**X**, **γ**, **β** and **n**
IEC 62387:2020	12 keV – 7 MeV, $H(10)$ 8 keV – 1.25 MeV, $H(0.07)$ 8 keV – 7 MeV, $H(3)$	0,01 mSv – 10 Sv	passive	personal workplace environment	**X**, **γ** and **β**
IEC 60846-1:2009	12 keV – 10 MeV, $H^*(10)$ 8 keV – 250 keV $H'(0.07)$	0,01 µSv - 10 Sv 0,01 µSv/h – 10 Sv/h	active (portable)	workplace environment	**X**, **γ** and **β**
IEC 60846-2:2015	up to 10 MeV	1 mSv/h – 10 Sv/h up to 10 Sv	active (portable)	workplace (accident, post-accident)	**X**, **γ** and **β**
IEC 60532:2010	50 keV – 7 MeV	N/A	active (installed)	workplace (NPP, NF safety)	**X** and **γ**
IEC 61017:2016	50 keV – 7 MeV	30 nSv/h – 30 µSv/h 10 nSv – 10 mSv	active (portable/installed)	environment	**X** and **γ**
IEC 62327:2017			active (portable) +identifiers	workplace	**X** and **γ** (**n**-optional)

Active Personal Dosemeters including Hybrid dosemeters

IEC 61526:2024 Radiation protection instrumentation – Measurement of personal dose equivalents for X, gamma, neutron and beta radiations – Active personal dosemeters

This standard applies to active, (direct reading or hybrid) personal dosemeters and monitors used for measuring personal dose equivalents $H_p(10)$, $H_p(3)$, and $H_p(0,07)$, for X, gamma, neutron, and beta radiations.

For personal dose equivalent $H_p(10)$ and for X and gamma radiation, two minimum rated ranges for the photon energy are given. The first from 20 keV to 150 keV is for workplaces where low energy X-rays are used, e.g., in diagnostic medicine, the second from 80 keV to 1,25 MeV is for workplaces where high energy X-rays and/or gamma sources are used, e.g., in industry. For neutron radiation the minimum rated range of neutron energy is from 0,025 eV (thermal neutrons) to 10 MeV. The rated ranges can be extended to all energies covered by the respective standards for reference radiation fields.

For personal dose equivalent $H_p(3)$ and for X and gamma radiation, a minimum rated range for photon energy from 30 keV to 250 keV is given. For personal dose equivalent $H_p(0,07)$ a range of 30 keV to 1250 keV or, for workplaces where low energy X-rays are used, 20 keV to 150 keV, is given. For beta radiation for both quantities, the minimal rated range is from 0,24 MeV to 0,8 MeV (mean beta particle energy). The rated ranges can be extended to all energies covered by the respective standards for reference radiation fields.

In cases of using dosemeters at a nuclear reactor installation, measurement of personal dose equivalent (rate) $H_p(10)$ for photon energies up to 10 MeV should be required.

Passive Personal Dosemeters and **Passive Dosimetry Systems for environment and working place monitoring** are covered by the same standard:

IEC 62387:2020 Radiation protection instrumentation - Dosimetry systems with integrating passive detectors for individual, workplace and environmental monitoring of photon and beta radiation

IEC 62387:2020 applies to all kinds of passive dosimetry systems that are used for measuring:

- the personal dose equivalent $H_p(10)$ (for individual whole body monitoring),
- the personal dose equivalent $H_p(3)$ (for individual eye lens monitoring),
- the personal dose equivalent $H_p(0,07)$ (for both individual whole body skin and local skin for extremity monitoring),
- the ambient dose equivalent $H^*(10)$ (for workplace and environmental monitoring),
- the directional dose equivalent $H'(3)$ (for workplace and environmental monitoring), or

- the directional dose equivalent $H'(0,07)$ (for workplace and environmental monitoring).

This document applies to dosimetry systems that measure external photon and/or beta radiation in the dose range between 0,01 mSv and 10 Sv and in the energy ranges given in Table 1. The dosimetry systems usually use electronic devices for the data evaluation and thus are often computer controlled.

Depending on the depth d, different minimum rated ranges of photon energies are defined. For all the test ranges the limits of variation are set from - 29 % to + 67 %, in terms of relative energy response, relative to S-Cs reference condition. Advised N-series (from N-15 up to N-300), S-Cs, S-Co, R-C (4,4 MeV) and R-F (6,7 MeV) from ISO 4037:2019 are to be used for the energy dependence test.

For the personal and directional dose equivalents (for $d = 3$ mm or $d = 0,07$ mm) N-10 radiation quality is also proposed for this test. The minimum rated range of photon energy for the $H_p(10)$ and $H^*(10)$ is the 80 keV - 1,25 MeV. Differentiation between ionizing radiation applications is not done in terms of energy response, so the same test range of photon energies is used for all practices. In contrast to the IEC 61526 where N-series are proposed as the preferred radiation qualities, in this standard these radiation qualities are clearly indicated for each operational quantity. For the extremities ($H_p(0,07)$ and $H'(0,07)$) rated range for photons is set from 30 keV to 250 keV with the same limits of variation as for whole body operational quantities. The rated ranges for active (IEC 61526) and passive (IEC 63287) dosimeters for extremity monitoring are significantly different, even though both cover the lower photon energies. Monitoring in terms of $H_p(3)$ is not included in the 3rd edition of IEC 61526 (as noted previously, the 4th edition from 2024 incorporated requirements for APDs measuring this quantity). The requirements set for passive dosimetry systems which measure this quantity are defined for the minimum rated range from 30 keV up to 1,25 MeV. As per the interpretation of the results and the inequality for the relative response, limits of variation are expanded with the combined expanded uncertainty of the conventional true value. No difference in terms of energy response is observed for individual and area monitoring with passive dosimetry systems.

Active area dosemeters for environment monitoring

IEC 60846-1:2009 Radiation protection instrumentation - Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation - Part 1: Portable workplace and environmental meters and monitors

This part of IEC 60846 series applies only to portable meters and monitors which are intended to be used in both the workplace and the environment. It applies to devices that measure the dose equivalent or dose equivalent rate from external beta and/or X and gamma radiation in the dose range between 0,01 µSv and 10 Sv and the dose rate range between 0,01 µSv h^{-1} and 10 Sv h^{-1} and in the energy ranges given in

the Table 1. All the energy values are mean energies with respect to the prevailing dose quantity.

IEC 61017:2016 Radiation protection instrumentation - Transportable, mobile or installed equipment to measure photon radiation for environmental monitoring

This standard is applicable to transportable, mobile or installed assemblies intended to measure environmental air kerma rates or air absorbed dose rates from 30 nGy·h^{-1} to 30 µGy·h^{-1} or ambient dose equivalent rates from 30 nSv·h^{-1} to 30 µSv·h^{-1}, or air kerma or air absorbed dose from 10 nGy to 10 mGy, or ambient dose equivalent from 10 nSv to 10 mSv, due to photon radiation of energy between 50 keV and 7 MeV. The measurable range of dose and dose rate can be extended by agreement between the purchaser and the manufacturer. This extension may be realized by combining more than one detector, for example NaI(Tl) scintillator and ionization chamber. For most environmental applications, instruments may measure over a more limited energy range of 80 keV to 3 MeV.

If the assembly is to be used to measure these quantities in the area surrounding a nuclear reactor producing 6 MeV radiation from the ^{16}N isotope, it will be necessary to determine the response at this energy. An absorbed dose in air, which uses the same unit, Gy, as air kerma can be taken to have the same numerical value as air kerma under the condition of electron equilibrium.

The requirements specified in this standard relate to normal operations of the assembly. Should an assembly be required for emergency conditions on-site at nuclear facilities then the requirements of IEC 60846-2 should also be applied to the assembly, particularly with regard to overload characteristics. The requirements for portable work place monitors to measure ambient and/or directional dose equivalent (rate) are specified in IEC 60846-1.

Active area dosemeters for working place monitoring

In additional to the IEC 60846-1 that used for the active area dosemeters for environment monitoring this type of the measurement devices can be covered by IEC 62327 for RIDs and by IEC 60532 for installed devices.

IEC 62327:2017 Radiation protection instrumentation - Hand-held instruments for the detection and identification of radionuclides and for the estimation of ambient dose equivalent rate from photon radiation. This standard defines requirements for a specific group of devices termed as Radionuclide Identifying Devices (RIDs), which are also portable area radiation monitoring instruments. In the scope of the standard is clearly stated that it does not cover the devices regulated by IEC 60846 series. Energy dependence of these devices is tested with the reference conditions being either Cs-137, Co-60 or Am-241. The limits of variation are set in terms of relative intrinsic error and are set to ± 30 %. If the

manufacturer states that RIDs can be used for radiation protection, then its properties should be following requirements either defined in IEC 60846-1 or IEC 60846-2.

This type of instrument also includes those used to detect the illicit trafficking of radioactive material which is covered by the following standards:

Table 3 IEC standards concerning instruments for the detection of illicit trafficking of radioactive material

Type of instrumentation	IEC number	Title of the standard
Body-worn	62401	Radiation protection instrumentation – Alarming Personal Radiation Devices (PRDs) for the detection of illicit trafficking of radioactive material
	62618	Radiation protection instrumentation – Spectroscopy-Based Alarming Personal Radiation Devices (SPRD) for detection of illicit trafficking of radioactive material
	62694	Radiation protection instrumentation – Backpack-type radiation detector (BRD) for detection of illicit trafficking of radioactive material
Portable or hand-held	62327	Radiation protection instrumentation – Hand-held instruments for the detection and identification of radionuclides and for the estimation of ambient dose equivalent rate from photon radiation
	62533	Radiation protection instrumentation – Highly sensitive hand-held instruments for photon detection of radioactive material
	62534	Radiation protection instrumentation – Highly sensitive hand-held instruments for neutron detection of radioactive material
Portal	62244	Radiation protection instrumentation – Installed radiation portal monitors (RPMs) for the detection of illicit trafficking of radioactive and nuclear materials
	62484	Radiation protection instrumentation – Spectroscopy-based portal monitors used for the detection and identification of illicit trafficking of radioactive material
Data format	62755	Radiation protection instrumentation – Data format for radiation instruments used in the detection of illicit trafficking of radioactive materials

IEC 60532:2010 Radiation protection instrumentation - Installed dose rate meters, warning assemblies and monitors - X and gamma radiation of energy between 50 keV and 7 MeV

This International Standard applies to installed dose rate meters, warning assemblies and monitors that are used to prevent or mitigate minor radioactive releases or fuel degradation within nuclear power plants /nuclear facility design bases. It also applies to systems used to warn personnel or ensure their safety during or following events that involving the release of radioactivity or risk of radiation exposure in nuclear power plants (NPP) or nuclear facility (NF),

This equipment is typically classified as category “A” or “B” or “C” or “not classified” in IEC 61226. It covers equipment intended to isotropically measure air kerma, ambient dose equivalent or other exposure quantities due to X or gamma radiation of energy between 50 keV and 7 MeV. The equipment is intended primarily for the purpose of radiological protection, and may play an auxiliary or indirect role in the achievement or maintenance of nuclear plant safety.

Instruments measuring over a more limited energy range fall within the scope of this standard provided they cover at least the range of 80 keV to 1,5 MeV.

Assemblies of this type are commonly defined as area radiation monitors. They are typically used to continuously monitor the radiological situation in working areas where the radiation field may change over time. Examples of such areas include nuclear power plants, particle accelerators, high active laboratories and fuel reprocessing plants. They also provide alarms when the radiation field exceeds predetermined limits. They are employed in safety-related protection systems, such as personnel access control systems which allow access to areas which can be subject to radiation fields.

Active dosemeters used in an emergency

IEC 60532:2010 Radiation protection instrumentation - Installed dose rate meters, warning assemblies and monitors - X and gamma radiation of energy between 50 keV and 7 MeV

This equipment is typically classified as category "A" or "B" or "C" or "not classified" in IEC 61226, may be installed in facilities such as nuclear power plants, nuclear fuel storage and processing sites, and thus may play a role in the achievement or maintenance of nuclear power plant safety. Compliance with IEC 61513 is required for monitors used in nuclear power plants.

IEC 60846-2:2015 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

This part of IEC 60846 applies to portable or transportable dose equivalent (rate) meters and/or monitors for the measurement of ambient and/or directional dose equivalent (rate) from external beta, X and gamma radiation for energies up to 10 MeV during emergency situations. With the exception of modified or new clauses listed in this standard, all clauses in IEC 60846-1:2009 are applicable for instruments used for emergency purposes.

Although this International Standard specifies the requirements for instruments primarily for emergency use, such instruments may also be used for on-site measurements at other times. If the instrument has a remote detector and if an additional detector is provided in the measuring assembly to measure dose equivalent rate at the location of the operator, the requirements apply to both of the detectors.

Pulsed fields

In case of using dosimeters in pulsed fields of ionizing radiation, it is necessary to comply with the requirements set out in Technical Specifications **IEC TS 63050** *"Radiation protection instrumentation – Dosemeters for pulsed fields of ionizing"* radiation or **IEC TS 62743** *"Radiation protection instrumentation – Electronic counting dosemeters for pulsed fields of ionizing radiation"*.

The specification and determination of the special characteristics required for dosemeters to be used in pulsed fields of ionizing radiation have been excluded from all standards for direct reading personal and environmental dosemeters issued before 2015 for radiation protection purposes. These standards only specify characteristics for continuous radiation. The concept is similar to the approach taken for other influence quantities, e.g., radiation energy.

Technical Specification IEC TS 63050 is a generalized version of IEC TS 62743 and not limited to dosemeters using pulse counting techniques. IEC TS 63050 might replace IEC TS 62743 in the future.

Additional standards

Almost all standards covered radiation protection dosemeters include following additional standards:

Electromagnetic compatibility

IEC 61000-4-2:2008, Electromagnetic compatibility (EMC) – Part 4-2: Testing and measuring techniques – Electrostatic discharge test

IEC 61000-4-3:2006, Electromagnetic compatibility (EMC) – Part 4-3: Testing and measuring techniques – Radiated, radio-frequency, electromagnetic field immunity test

IEC 61000-4-4:2004, Electromagnetic compatibility (EMC) – Part 4-4: Testing and measuring techniques – Electrical fast transient (burst immunity) test

IEC 61000-4-5:2005, Electromagnetic compatibility (EMC) – Part 4-5: Testing and measuring techniques – Surge immunity test

IEC 61000-4-6:2008, Electromagnetic compatibility (EMC) – Part 4-6: Testing and measuring techniques – Immunity to conducted disturbances induced by radio-frequency fields

IEC 61000-4-8, Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test

IEC 61000-4-11, Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests

IEC 61000-4-12, Electromagnetic compatibility (EMC) – Part 4-12: Testing and measurement techniques – Ring wave immunity test

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

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

Documentation

IEC 61187:1993, Electrical and electronic measuring equipment – Documentation