ANNEX 1

Requirements for radiation measurement reliability, radiation meters and measurement systems

Table 1.1. Purpose of the measurement, measuring quantities, measurement accuracy requirements and the requirements imposed on radiation meters and measurement systems.

Purpose of measurement	Measured quantity	Maximum permissible uncertainty of measurement (%)[1]	Radiation meter[2] or measuring system requirements
Radiological surveillance. Dose or dose rate measurement in the working premises or their vicinity[3]	Ambient dose equivalent Ambient dose equivalent rate	60	With photon radiation, the response of the meter[3] may not be lower than 0.71 or higher than 1.67 in the energy range 20 keV—150 keV or 80 keV—1.5 MeV The intrinsic error of an alarming personal dosemeter may not exceed 30%
Radiological surveillance. Dose or dose rate measurement in the working premises or their vicinity[3]	Directional dose equivalent Directional dose equivalent rate	60	The intrinsic error of an alarming personal dosemeter may not exceed 30%
Radiological surveillance X-ray diagnostics equipment leakage and scatter radiation	Air kerma rate	20	
Radiological surveillance Radioactive substance contamination in the working premises or their vicinity	Surface activity	60	
Individual monitoring. A dosimetry system shall be used for determining the worker's dose	Personal dose equivalent	42	The highest variation range of response R [4] With photon radiation, $\overline{E}_{ph} > 10$ keV, and with beta radiation, $\overline{E}_{beta} > 0.2$ MeV $0{,}71 \cdot \left[1 - \dfrac{2 \cdot H_0/1{,}33}{H_0/1{,}33 + H_{ref}}\right] \le R$ [5] $1{,}67 \cdot \left[1 + \dfrac{H_0}{4 \cdot H_0 + H_{ref}}\right] \ge R$ With neutron radiation and photon radiation, $\overline{E}_{ph} \le 10$ keV, and with beta radiation, $\overline{E}_{beta} \le 0.2$ MeV $0{,}5 \cdot \left[1 - \dfrac{2 \cdot H_0/1{,}5}{H_0/1{,}5 + H_{ref}}\right] \le R \le 2$

Purpose of measurement	Measured quantity	Maximum permissible uncertainty of measurement (%)[1]	Radiation meter[2] or measuring system requirements
Determination of a radiation worker's dose from internal exposure. Activity measurement	Nuclide-specific activity	Uncertainty in accordance with the standard applicable to the method of determination	In accordance with the standard applicable to the method of determination
Determination of a radiation worker's dose from internal exposure. Dose determination	Committed effective dose	Uncertainty in accordance with the standard applicable to the method of determination	In accordance with the standard applicable to the method of determination
Building material measurements	Activity concentration	Uncertainty in accordance with the standard applicable to the method of determination	The activity concentration of building materials shall be measured using high energy resolution (HPGe) gamma spectrometry.

[1] Expanded uncertainty of measurement with coverage factor 2.

[2] The measuring instrument shall meet the requirements set out in the applicable standard.

[3] The requirement concerns external radiation exposure.

[4] $R = \frac{G}{H_{ref}}$ is the dosemeter response, where G is the dose determined with the dosemeter and H_{ref} is the actual dose.

[5] H_{ref} is the recording level.

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Table 1.2. Quantities and accuracy requirements used in measurements carried out for determining medical exposure.

Purpose of measurement	Measured quantity	Maximum permissible uncertainty of measurement (%)[1]	Radiation meter requirements
X-ray examinations and procedures. X-ray equipment radiation output.	Air kerma Current time product	7	A measuring instrument that meets the criteria referred to in IAEA TRS 457[2]
X-ray examinations and procedures	Entrance surface air kerma Air kerma-area product	25[3]	A measuring instrument that meets the criteria referred to in IAEA TRS 457[2]
CT scans and procedures	Air kerma-length product Volume CT air kerma index	25[3]	A measuring instrument that meets the criteria referred to in IAEA TRS 457[2]
External radiotherapy with photon radiation under reference conditions[4]	Absorbed dose to water	3	A measuring instrument that meets the criteria referred to in IAEA TRS 398:n[5]
External radiotherapy with electron radiation under reference conditions[4]	Absorbed dose to water	4	A measuring instrument that meets the criteria referred to in IAEA TRS 398:n[5]
External radiotherapy. Measurement in patient	Absorbed dose to water	5	
Brachytherapy with a photon radiation source under reference conditions[4]	Reference air kerma rate	5	Applicable international standard
Brachytherapy with a beta radiation source under reference conditions[4]	Reference dose rate for absorbed dose to water	15	Applicable international standard

[1] Expanded uncertainty of measurement with coverage factor 2.

[2] International Atomic Energy Agency (IAEA). Dosimetry in diagnostic radiology: An international code of practice Technical report series no. 457. Vienna: IAEA, 2007.

[3] The same maximum value for uncertainty shall also be used when the apparatus is equipped with a computational indication of the patient's radiation exposure.

[4] Reference conditions mean measurement in water, in reproducible and known geometry and environmental conditions, the result of which is used as the basis for the patient's dose determination and planning.

[5] International Atomic Energy Agency (IAEA). Absorbed dose determination in External Beam Radiotherapy. An international code of practice for Dosimetry Based on Standards of Absorbed Dose to Water. Technical reports series no. 398, V12, 05 June 2006 or a later edition.

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Table 1.3. Measurement quantities used in rescue operations and civil defence and requirements for measuring photon radiation and for radiation meters.

Purpose of measurement	Measured quantity	Measurement range[1]	Radiation meter requirements
Rescue operations	Ambient dose equivalent rate[2]	Minimum for dose equivalent rate 0.1 µSv/h—10 Sv/h	Meets the requirements of IEC 60846-2[2] Protection against dust and water: Ingress protection rating IP 65 (according to SFS-EN 60529) If the radiation meter can be fitted with a separate surface contamination sensor, it must meet the requirements of IEC 60325
Civil defence	Ambient dose equivalent rate[2]	Minimum for dose equivalent rate 1 µSv/h—100 mSv/h	Meets the requirements of IEC 60846-1[2] Protection against dust and water: Ingress protection rating IP 54 (according to SFS-EN 60529)
Personal dose measurement	Personal dose equivalent Personal dose equivalent rate	Minimum for dose equivalent rate 0.5 µSv/h–1 Sv/h	Meets the requirements of IEC 61526 Protection against dust and water: Ingress protection rating IP 54 (according to SFS-EN 60529)

[1] If it is not possible to cover the entire measurement range with one radiation meter, several radiation meters can be used, whose combined measurement range covers the required measurement range.
[2] If the portable dose rate meter also has a dose-measuring capability, the dose-measuring capability of the dosimeter shall meet the requirements of the standard.

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Table 1.4. Requirements for the measurement of radon concentration and radon-induced exposure.

Measurement and its purpose	Measured quantity and measurement unit	Maximum permissible uncertainty of measurement (%)[1]	Requirements for radiation meter or measurement system
Continuous integrated measurement of indoor radon concentration for at least 2 months in a workplace, dwelling and other premises used by people	Activity concentration (Bq/m^3)	30	The coefficient of variation of the results shall not exceed 10 % for an exposure corresponding to an activity concentration of 300 Bq/m^3 and 1500 hours of measurement. The coefficient of variation of the distribution of the results is determined from the readings of several integrating meters under constant conditions (homogeneity)[2]. The upper limit of the measurement range shall be at least 5 000 Bq/m^3 if the meter is used for comparison with a radon reference level at the workplace or in the dwelling and the measurement is carried out over a period of at least 60 days. The upper limit of the measurement range shall be at least 10 000 Bq/m^3 if the measurement result is used to calculate the dose to a worker and the measurement period is at least 60 days.
Continuous measurement over a period of at least one week for investigating temporal variations of indoor radon concentrations	Activity concentration (Bq/m^3)	30	The sensitivity of the meter shall be at least 0.01 cph/(Bq/m^3). The response time of the meter shall not exceed 100 min. The upper limit of the measurement range shall be at least 9 000 Bq/m^3 if the measurement result is used to determine the radon concentration during working hours and full-time and the measurement is performed with a measurement period of at least 7 days.
Instantaneous measurement of radon in air lasting for up to 1 hour	Activity concentration (Bq/m^3)	30	The coefficient of variation of the results shall not exceed 10 % at an activity concentration of 300 Bq/m^3. The coefficient of variation of the distribution of the results is determined from the repeated readings of the measurement (repeatability)[2]. The upper limit of the measurement range shall be at least 10 000 Bq/m^3 if the dose to a worker is calculated from the measurement result.

Measurement and its purpose	Measured quantity and measurement unit	Maximum permissible uncertainty of measurement (%)[1]	Requirements for radiation meter or measurement system
Individual integrated measurement of at least 2 months to determine the worker's exposure to radon	Radon exposure (Bq h/m³)	30	Coefficient of variation of the results shall not exceed 10% at 500 000 Bq h/m³ exposure. The coefficient of variation of the distribution of the results is determined from the readings of several integrating instruments under standard conditions (homogeneity)[2]. The upper limit of the measurement range of the meter and the measurement system for measuring occupational exposure to radon shall be at least 3 000 000 Bq h/m³.
Measurement with a portable meter of less than 2 months to determine the worker's exposure to radon	Activity concentration (Bq/m³)	30	Meter sensitivity of at least 0.01 cph/(Bq/m³). The upper limit of the measurement range shall be at least 10 000 Bq/m³ if the dose to the worker is calculated from the measurement result and the measurement is performed with a shorter measurement period than 60 days.
[1] Expanded uncertainty of measurement with coverage factor 2. [2] The coefficient of variation does not consider statistical variation due to radon decay.			

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ANNEX 2

Quantity definitions

Air kerma

Air kerma (K_a) is the sum of the initial kinetic energies of the charged particles produced by uncharged ionizing particles in a small element of air, divided by the mass of that element of air.

The unit of air kerma is the gray (Gy), 1 Gy = 1 J·kg^{-1}.

Air kerma rate is the increase in air kerma over a short interval divided by that interval.

Dose equivalent

The dose equivalent H is the product of the absorbed dose D and the quality factor Q:

$H = Q{\cdot}D$.

The unit of dose equivalent is the sievert (Sv).

The quality factor Q is a factor which depends on the linear energy transfer L, and which seeks to allow for the different ability of various radiation qualities to cause damage to health.

The dependency between Q and L is shown in Table 2.1.

Table 2.1. Quality factor Q as a function of linear energy transfer L.

Linear energy transfer L in water (keVμm^{-1})	Quality factor Q (L)
< 10	1
10–100	0.32 L - 2.2
> 100	300 / √ L

When the absorbed dose at a point in tissues is caused by particles of varying linear energy transfer, the quality factor can be calculated as a mean quality factor by considering the distribution of the absorbed dose in relation to the linear energy transfer. The linear energy transfer means the unrestricted linear energy transfer.

Directional dose equivalent

The directional dose equivalent $H'(d,\Omega)$ is the dose equivalent at a point in a radiation field which would be caused by the corresponding expanded field in an ICRU sphere at a depth d on a radius in a specified direction Ω, where:
1) an expanded field is a radiation field in which the particle fluence and its directional and energy distributions are the same throughout the volume of interest as at the reference point in the actual field;
2) The ICRU sphere is a spherical tissue equivalent defined by the International Commission on Radiation Units and Measurements (ICRU), which approximately corresponds to the human body with regard to the absorption of the energy of ionizing radiation.

The unit of directional dose equivalent is the sievert (Sv).

Ambient dose equivalent

The ambient dose equivalent $H^*(d)$ is the dose equivalent at a point in a radiation field which would be caused by the corresponding aligned and expanded field in an ICRU sphere at a depth d on the radius opposing the direction of the aligned field, where:

1) an aligned and expanded field is a radiation field in which the particle fluence and its energy distribution are the same as in the expanded field, but the fluence is unidirectional.
2) The ICRU sphere is a spherical tissue equivalent defined by ICRU, which approximately corresponds to the human body with regard to the absorption of the energy of ionizing radiation.

The unit of ambient dose equivalent is the sievert (Sv).

Personal dose equivalent

The personal dose equivalent $H_\mathrm{p}(d)$ is the dose equivalent at a point at depth d in soft tissues of the body.

The unit of personal dose equivalent is the sievert (Sv).

Surface activity

The surface activity A_s is the activity A of a radioactive substance on a given surface in the area under inspection, divided by the area S of this surface:

The unit of surface activity is $Bq \cdot m^{-2}$.

Entrance surface air kerma

The entrance surface air kerma (*ESAK*) is air kerma at the point of intersection of the central axis of the radiation beam with the entrance surface of the patient, including radiation scattered from the patient to this point.

The unit of entrance surface air kerma is the gray (Gy).

Air kerma-area product

The air kerma-area product (*KAP*) is defined as an integral

$$KAP = \int_{A_M} K(x, y)\, dxdy \, ,$$

where $K(x,y)$ is the air kerma on a plane perpendicular to the axis of the radiation beam and A_M is the integration area.

The unit of air kerma-area product is $Gy \cdot m^2$ (or more commonly $Gy \cdot cm^2$).

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Air kerma-length product
In tomography imaging, the air kerma-length product is defined as an integral

$$KLP = \int_{-\infty}^{\infty} K(z)\ dz,$$

where *K(z)* on the air kerma arising from the examination as a function of place *z* (the air kerma profile) in the direction of the axis of rotation of the X-ray tube.

The unit of air kerma-length product is Gy·m (or more commonly Gy·cm).

Based on the air kerma profile of an individual axial imaging or single rotation of the X-ray tube, the *KLP* is

$$KLP = N \cdot \int K_1(z) dz = N \cdot KLP_1,$$

where
$K_1(z)$ is the air kerma profile of an individual axial imaging or single rotation of the X-ray tube, and KLP_1 the corresponding air kerma-length product;
N is the number of rotations of the X-ray tube.

Weighted air kerma-length product
The weighted air kerma-length product (KLP_w) is defined as follows:

$$KLP_w = \frac{1}{3} \cdot KLP_c + \frac{2}{3} \cdot KLP_p,$$

where KLP_c is the air kerma-length product determined in the middle of a tissue equivalent used in computed tomography and KLP_p is the air kerma-length product determined at a depth of 10 mm in said tissue equivalent.

Volume CT air kerma index
In computed tomography examinations (CT scans) consisting of several individual axial images or several individual rotations of the X-ray tube in helical scanning, the volume CT air kerma index is:

$$CTKI_{vol}\ = \frac{1}{d}\int_{-\infty}^{\infty} K(z)\ dz = \frac{1}{d} KLP,$$

where *K(z)* is the air kerma profile, as defined in the standard tissue equivalent used in CT scans, caused by the entire examination in the monitored area in the direction (*z*) of the axis of rotation of the X-ray tube and at the monitored distance from said axis;
d is the length of the examined area in the direction of said axis.

The unit for volume CT air kerma index is Gy (or more commonly mGy).

The volume CT air kerma index calculated from the air kerma profile $K(z)$ measured during a single axial imaging or one rotation of the X-ray tube in helical scanning and from the corresponding table movement $\triangle d$ is:

$$CTKI_{vol} \; = \; \frac{1}{\triangle d} \int_{-\infty}^{\infty} K(z) \; dz$$

Calculated using the weighted air kerma-length product, the CT air kerma index is:

$$CTKI_{vol} = \frac{1}{d} KLP_w$$

In practical measurements, the integration limits are finite.

Reference air kerma rate
The reference air kerma rate is the air kerma rate at a distance of one metre from a brachytherapy radiation source.

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