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Nuclear energy — Radioprotection — Procedure for radiation protection monitoring in nuclear installations for external exposure to weakly penetrating radiation, especially to beta radiation

Énergie nucléaire — Radioprotection — Procédure de surveillance dosimétrique de radioprotection dans les installations nucléaires pour l'exposition externe aux rayonnements faiblement pénétrants, en particulier au rayonnement bêta

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15382 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

Annexes A to C of this International Standard are for information only.

Introduction

A high percentage of weakly penetrating radiation, mainly beta radiation, has to be expected in nuclear power plants, especially during maintenance work. Special rules need to be respected and particular protection procedures are required for external exposure to this radiation. Dosimetry methods usually applied in radiation protection monitoring of strongly penetrating radiation cannot be directly applied to weakly penetrating radiation.

Exposures of persons to weakly penetrating radiation are mainly caused by unshielded open radioactive sources. This type of exposure may occur, in particular, in connection with contamination. Nuclear installations may involve large-area contamination with locally different nuclide composition, which can vary with time. In addition, the activity per unit area may assume high values. Exposure to weakly penetrating radiation from radioactive noble gases in room air has also to be considered. Particular attention has to be paid to work performed on heavily contaminated parts at close proximity. This requires special rules and procedures for the nuclear power plants, some of which may be applicable to the handling of radioactive sources in other disciplines.

In order to achieve and maintain high radiation protection standards, it is necessary to utilize a special standard dedicated to the particular concern pertaining to protection against, and monitoring of, external exposures to weakly penetrating radiation.

Nuclear energy — Radioprotection — Procedure for radiation protection monitoring in nuclear installations for external exposure to weakly penetrating radiation, especially to beta radiation

1 Scope

This International Standard specifies a procedure for radiation protection monitoring in nuclear installations for external exposure to weakly penetrating radiation, especially to beta radiation and describes the procedure in radiation protection monitoring for external exposure to weakly penetrating radiation in nuclear installations. This radiation comprises β^- radiation, β^+ radiation and conversion electron radiation as well as photon radiation with energies below 15 keV. This International Standard describes the procedure in radiation protection planning and monitoring as well as the measurement and analysis to be applied. It applies to regular nuclear power plant operation including maintenance, waste handling and decommissioning.

The recommendations of this International Standard may also be transferred to other nuclear fields including reprocessing, if the area-specific issues are considered. This International Standard may also be applied to radiation protection at accelerator facilities and in nuclear medicine, biology and research facilities.

2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 6980:1996, *Reference beta radiations for calibrating dosemeters and dose-rate meters and for determining their response as a function of beta-radiation energy*

3 Terms and definitions

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

3.1 Quantities and units

3.1.1
equivalent dose in a tissue or organ
H_T
product of the absorbed dose $D_{T,R}$, averaged over the tissue or organ T, in the case of skin averaged over the whole surface, and the relevant radiation weighting factor w_R for the radiation R

$$H_T = w_R \cdot D_{T,R}$$

NOTE 1 When the radiation fields are composed of radiations with different values of w_R, the equivalent dose in a tissue or organ is the sum of the products of the radiation weighting factor w_R and the absorbed dose, $D_{T,R}$, thus

$$H_T = \sum_R w_R \cdot D_{T,R} \quad (1)$$

NOTE 2 The equivalent dose quantities defined in "Equivalent dose in a tissue or organ" cannot be directly measured. Instead, the dose equivalent is measured with dosimeters positioned on appropriate parts of the body. These dosimeters are calibrated on appropriate phantoms.

NOTE 3 The unit of equivalent dose in a tissue or organ is joule per kilogram ($J \cdot kg^{-1}$) with the special name sievert (Sv).

NOTE 4 For β and photon radiation, the numerical values of dose equivalent and equivalent dose are practically the same.

3.1.1.1
partial-body dose
equivalent dose to tissue, organs or parts of the body identified by the name of the part of the particular tissue, organ or body, e.g. bone marrow dose, skin dose, hand dose, testes dose or dose to the lens of the eyes

NOTE 1 In regulations still based on ICRP 26[1], the dose equivalent to a part of the body or organ, H_T, is defined, for beta and photon radiation, as the product of the absorbed dose, D_T, in the organ and the quality factor Q for the radiation under consideration. Q is defined as a function of the linear collision stopping power in water; for low energy photons, and for beta particles Q is equal to 1 in this International Standard.

NOTE 2 The unit of partial-body dose is joule per kilogram ($J \cdot kg^{-1}$), with the special name sievert (Sv).

3.1.1.2
localized skin dose
H_{skin}
equivalent dose averaged over an area of 1 cm^2 of skin at a nominal depth of 0,07 mm and at the respective point of interest

NOTE 1 The maximum localized skin dose is predominant in monitoring the skin limit for external radiation.

NOTE 2 The unit of localized skin close is joule per kilogram ($J \cdot kg^{-1}$), with the special name sievert (Sv).

3.1.2
effective dose
E
sum of the equivalent doses, H_T, in relevant organs and tissues multiplied by the appropriate tissue weighting factors, w_T

$$E = \sum_T w_T \cdot H_T$$

NOTE 1 The following expression applies based on the definition of H_T.

$$E = \sum_T \sum_R w_T \cdot w_R \cdot D_{T,R} \quad (2)$$

NOTE 2 The equivalent dose quantities defined in “Effective dose“ cannot be directly measured. Instead the dose equivalent is measured with dosimeters positioned on appropriate parts of the body. These dosimeters are calibrated on appropriate phantoms.

NOTE 3 The unit of effective dose is joule per kilogram ($J \cdot kg^{-1}$), with the special name sievert (Sv).

3.1.3
weighting factor
w_T
factor which represents the relative contribution of that organ or tissue to the total detriment due to the stochastic effects resulting from uniform irradiation of the whole body

3.1.4
effective dose equivalent
H_E
weighted average of the dose equivalent in a tissue or organ, T, each weighted by a tissue or organ weighting factor, w_T, as formerly recommended by ICRP 26 [1]

3.1.5
personal dose equivalent
$H_p(d)$
dose equivalent in soft tissue measured at an appropriate depth, d, below a specified point of the body

NOTE 1 For strongly penetrating radiation, the depth, 10 mm, is frequently recommended (see 3.3.1). For weakly penetrating radiation a depth of 0,07 mm for the skin and 3 mm for the lens of the eye are employed (see 3.3.1). For these purposes, $H_p(d)$, is written as, $H_p(10)$, $H_p(3)$ and $H_p(0,07)$, respectively

NOTE 2 This definition ensures that the personal dose equivalent, $H_p(10)$, for a whole-body exposure to strongly penetrating radiation, represents an estimate of the effective dose and the equivalent dose for deep-lying organs, whereas the personal dose equivalent, $H_p(0,07)$, permits the skin dose to be monitored for a partial-body exposure of the skin or of the extremities.

NOTE 3 The unit of personal dose equivalent is joule per kilogram ($J \cdot kg^{-1}$), with the special name sievert (Sv).

NOTE 4 As noted in ICRU 56[2], in most cases the only value of the depth that is of concern for beta radiation is 0,07 mm while in a few instances a depth of 3 mm is of interest for protection of the lens of the eye. The ambient dose equivalent $H^*(10)$ used for the monitoring of strongly penetrating radiation is not appropriate for any beta radiation, even that which is considered as strongly penetrating ($E_{max} > 2,5$ MeV) (see 3.1.6.1).

3.1.6
area monitoring
for purposes of routine radiation protection, it is desirable to characterize the potential irradiation of individuals in terms of a single dose-equivalent quantity that would exist in a phantom approximating the human body

NOTE 1 The phantom selected is called the ICRU sphere.

NOTE 2 For area monitoring, it is useful to stipulate certain radiation fields that are derived from the actual radiation field. The terms ”expanded” and ”aligned” are used to characterize these derived radiation fields. In the expanded field, the fluence and its angular and energy distribution have the same values throughout the volume of interest as in the actual field at the point of reference. In the aligned and expanded field, the fluence and its energy distribution are the same as in the expanded field but the fluence is unidirectional.

3.1.6.1
ambient dose equivalent
$H^*(d)$
dose equivalent that would be produced, at a point in a radiation field, by the corresponding aligned and expanded radiation field in the ICRU sphere at a depth, d, on the radius opposing the direction of the aligned field

NOTE 1 The recommended depth for strongly penetrating radiation is d = 10 mm.

NOTE 2 The ambient dose equivalent $H^*(10)$ is not suitable for measurements in pure beta radiation fields.

NOTE 3 The unit of ambient dose equivalent is joule per kilogram ($J \cdot kg^{-1}$), with the special name sievert (Sv).

3.1.6.2
directional dose equivalent
$H'(d,\Omega)$
dose equivalent that would be produced, at a point in a radiation field by the corresponding expanded radiation field in the ICRU sphere at depth, d, on a radius in a specified direction, Ω

NOTE 1 The recommended depth for weakly penetrating radiation is d = 0,07 mm.

NOTE 2 In an expanded radiation field with given directional radiation distribution, the value of the quantity, $H'(d)$, is generally dependent on the orientation of the specified sphere radius.

NOTE 3 The use of ambient and directional dose equivalents ensures that, for strongly penetrating radiation, the ambient dose equivalent gives an estimate of the effective dose and the equivalent dose in deep-lying organs and, for weakly penetrating radiation, the directional dose equivalent gives an estimate of a person's skin dose during measurement at the location where the dose is measured.

NOTE 4 The dose equivalent for area monitoring for strongly penetrating radiation is given by, $H^*(10)$, and for weakly penetrating radiation by, $H'(0,07)$. If strongly penetrating radiation and weakly penetrating radiation are considered simultaneously, the dose equivalent is characterized by the pair of values, $H^*(10)$ and $H'(0,07)$. This quantity definition corresponds approximately to the directional dependence of readings in measurements with an area dosimeter designed for simultaneous measurement of strongly and weakly penetrating radiation.

NOTE 5 The unit of directional dose equivalent is joule per kilogram ($J \cdot kg^{-1}$), with the special name sievert (Sv).

3.1.7
dose-equivalent rate
quotient of dose equivalent in a time interval divided by the time interval

NOTE 1 For area monitoring, the dose-equivalent rate for strongly penetrating radiation is given by $H^*(10)$, and for weakly penetrating radiation by $H'(0,07)$. If strongly penetrating radiation and weakly penetrating radiation have to be considered, the pair of values, $H^*(10)$ and $H'(0,07)$, should be reported

NOTE 2 The dose-equivalent rate is joule per kilogram ($J \cdot kg^{-1}$), with the special name sievert (Sv).

3.2 Personal dosimeters

3.2.1
approved dosimeter
personal dosimeter used to determine the personal dose equivalent and issued by a measurement office in compliance with national regulations

NOTE In some countries, the approved dosimeters are named official or accredited dosimeters.

3.2.2
approved whole-body dosimeter
approved dosimeter for measuring the personal dose equivalent due to whole-body exposure

NOTE The reading of the whole-body dosimeter worn on the front of the trunk is often used as an estimate of the effective dose.

3.2.3
approved partial-body dosimeter
approved dosimeter for measuring the personal dose equivalent to the part of the body concerned (see informative annex A)

NOTE The reading of the partial-body dosimeter is often used as an estimate of the dose equivalent for the affected part of the body.

3.3 Other terms

3.3.1
weakly penetrating radiation
radiation when the personal dose equivalent received by any small area of the sensitive layer of the skin is more than 10 times larger than the effective dose for a given orientation of the body in a uniform and unidirectional radiation field

3.3.2
strongly penetrating radiation
radiation when the equivalent dose received by any small area of the skin is less than 10 times larger than the effective dose for a given uniform and unidirectional field and orientation of the body

3.3.3
soft tissue
for dosimetry purposes, homogeneous material composed of (in weight percentages): 10,1 % hydrogen, 11,1 % carbon, 2,6 % nitrogen and 76,2 % oxygen ICRU tissue, with a specific gravity of 1 $g \cdot cm^{-3}$

NOTE For ICRU tissue see ICRU 33[3].

3.3.4
investigation level
value of the personal dose equivalent which, when exceeded, requires investigations into the effectiveness of radiation protection measures

NOTE 1 The investigation level is dependent on the respective operation or application type.

NOTE 2 The investigation level in this International Standard is a dose equivalent specified for various parts of the body for a fixed time period. For personal dose-equivalent readings below or equal the investigation level, the dosimeter reading is taken as representing the effective dose, or equivalent dose to specified organs or parts of the body. For a personal dose equivalent reading exceeding the investigation level, it needs to be verified whether a calculation of the corresponding equivalent dose is required.

NOTE 3 Investigation levels are established by national authorities.

3.3.5
transmission factor
T
ratio of the dose-equivalent rate determined behind a shielding and the dose-equivalent rate without this shielding

NOTE 1 For X-rays and gamma radiation, the attenuation factor, which is equal to the reciprocal of the transmission factor, is often used.

NOTE 2 In mixed beta and photon radiation fields, the transmission factor can also be specified for components of the radiation field.

NOTE 3 Reference should be made to the geometry for which the transmission factor is calculated or measured.

4 Radiation protection planning

Weakly penetrating radiation is to be expected in the vicinity of unsealed radioactive materials, for example, on contaminated inner surfaces of plant components, on system components or tools and in contaminated areas. High values of the directional dose-equivalent rate can be produced, in particular, by beta radiation. Therefore, weakly penetrating radiation should be considered already at the stage of radiation protection planning.

The components on which contamination can occur are, as a rule, known from operational experience. If a high gamma ambient-dose-equivalent rate is measured on closed components (e.g. pumps, steam generator), a high percentage of weakly penetrating radiation has to be expected when the component is opened.

The radiation fields from contaminated surfaces or air may be subject to considerable variation in time and location.

NOTE Information on weakly penetrating radiation, in particular beta radiation, in nuclear power plants is given in references [4] to [10] in the bibliography.

5 Characterization of radiation fields

5.1 Introduction

The effective dose from weakly penetrating radiation, in particular from beta radiation, depends on the directional dose-equivalent rate, the duration of the exposure, on the direction considered and the attenuation by the protective clothing. Information about the energy of beta radiation is obtained from the radionuclide composition, beta spectrometry or the attenuation of the radiation.

5.2 Nuclide composition of contamination

The composition of a radionuclide mixture can be determined, for example, by radiochemical analysis, by direct measurements with gamma spectrometers on surfaces or by the evaluation of wipe or scratch tests.

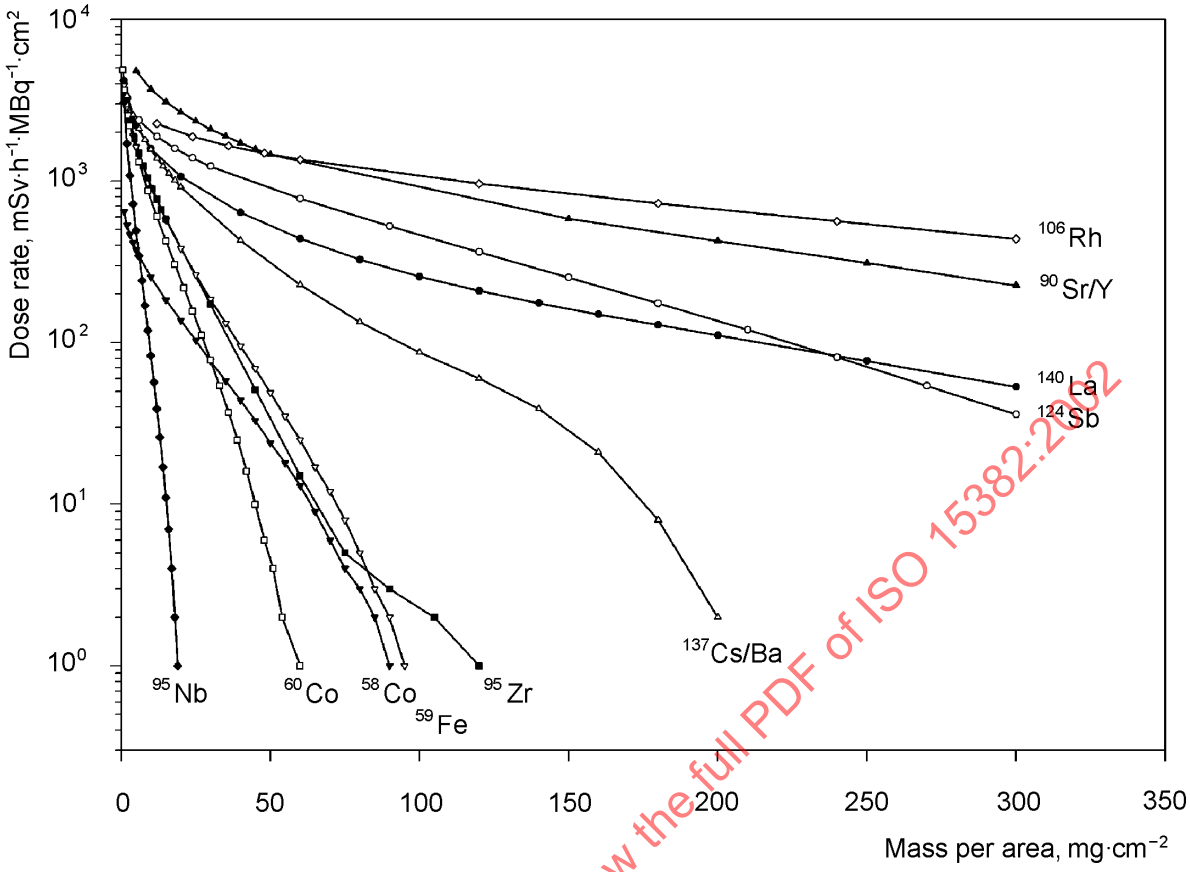
In determining the radionuclide composition, all radionuclides which contribute significantly to the directional dose equivalent due to the emission of weakly penetrating radiation shall be recorded.

NOTE 1 The radionuclide composition may be subject to variations in time and location.

NOTE 2 Wipe tests alone do not always provide the complete radionuclide spectrum, especially in the case of fixed contamination.

NOTE 3 Whereas weakly penetrating radiation is partially attenuated by absorbers (e.g. air), beta radiation components of high maximum energy (e.g. ^{124}Sb with $E_{\beta,\max}$ = 2,3 MeV) can contribute significantly to the dose equivalent even if their concentration in the radionuclide mixture is small (see Figure 1).

NOTE 4 Gamma spectrometers do not provide information on the complete radionuclide spectrum since pure beta emitters are not detected.



The gamma components of the radionuclides are not considered in the calculations. All calculations by Cross [10] were prior to the issue of ICRU 39 [11]

Figure 1 — Calculated beta dose-equivalent rates as a function of the mass per area of an absorber in front of extended sources for various radionuclides frequently present in nuclear power plants (Cross [10])

5.3 Attenuation of radiation

Attenuation measurements may be used to characterize the radiation field by estimation of the maximum energy of beta radiation (see Figure 2, 3.3.5 and 6.5).

6 Area dose-equivalent rate measurements

6.1 General

Weakly penetrating radiation primarily affects the skin. The International Commission on Radiological Protection (ICRP) considers it appropriate to limit skin exposure on the basis of a skin dose evaluated at a depth of 0,07 mm. The area dose-equivalent rate measurement relates to this tissue depth by measuring the directional dose-equivalent rate, $\dot{H}'(0{,}07,\Omega)$. In general, weakly penetrating radiation is accompanied by strongly penetrating radiation, which contributes to the dose both in the skin and in deeper tissue layers. This has to be taken into account in area dose-equivalent rate measurements by measuring the ambient dose-equivalent rate, $H^*(10)$.

If weakly penetrating radiation is expected, radiation protection measures always have to be based on measurements of the ambient dose-equivalent rate $H^*(10)$ and the directional dose-equivalent rate $\dot{H}'(0{,}07,\Omega)$ (see also 3.1.7). The results (possibly behind protective clothing as used by the radiation worker, see also 6.3) are used to determine whether the dose on the extremities according to 7.2 or the skin dose according to 7.3 should be measured.

6.2 Measuring requirements

Before starting to work on contaminated or activated objects, it is required to measure the dose-equivalent rates, $\dot{H}'(0,07)$ in addition to $\dot{H}^*(10)$.

Measurements of the directional dose-equivalent rate $\dot{H}'(0,07)$ are not required if it is known from radionuclide analysis, or from earlier measurements, that the exposure level for weakly penetrating radiation is very low or that the protective clothing is sufficient to shield this type of radiation.

For certain equipment or systems and in certain periods of time, $\dot{H}'(0,07)$ may be estimated by the known ratio of $\dot{H}'(0,07)/\dot{H}^*(10)$.

However, the measurements shall be repeated if new and possibly contaminated surfaces are accessible in the course of work.

6.3 Measuring instruments

For determining the directional dose-equivalent rate $\dot{H}'(0,07)$, dose-equivalent rate meters with thin-walled detectors should be used (see ICRU 56:1997, chapter 8, [2]).

Dose-rate meters with thin-walled ionization chambers are particularly suitable. Dose-rate meters with a small-volume ionization chamber may be used in close vicinity to a radiation source. Large-volume ionization chambers should be used where small dose rates are to be measured or a rapid reading is required. A possible need to correct for underestimation of $\dot{H}'(0,07)$ should be taken into account in measurements with large-volume ionization chambers due to non-uniform irradiation of the detector volume.

If protective clothing is worn, $\dot{H}'(0,07)$, should not be measured free in air but behind the respective layer of clothing.

Dose-equivalent rate meters with an ionization chamber measure the dose rate averaged over the chamber volume. The result of measurements at short distances from the contaminated surface depends on the size of the ionization chamber, and on the size of the contaminated area, due to the field gradient. The dose-equivalent rate can be underestimated by a factor of 5 to 10 (in extreme cases even more) when a large-volume ionization chamber (chamber volume of approx. 500 cm^3) is used near a contaminated surface. The factor depends on the distance, the area of contamination and the beta radiation energy (see [12], in the bibliography).

The directional dose-equivalent rate $\dot{H}'(0,07)$ may also be determined using instruments with other detectors, e.g. with surface-barrier detectors or scintillation counters (see [12] and [13] in the bibliography). Instruments with Geiger-Müller detector tubes are not suitable for determining the directional dose-equivalent rate $\dot{H}'(0,07)$.

An ionization chamber covered with a tissue-equivalent chamber wall or cap of 1 $g \cdot cm^{-2}$ is suitable for measuring $\dot{H}^*(10)$ of strongly penetrating radiation.

As for the quantity to be measured, the calibration of measuring instruments and dosimeters should be traceable to national standards.

6.4 Place of measurement

The place of measurement shall be representative for the exposure conditions of the person surveyed. If it cannot be avoided that contaminated objects are touched with the hands, measurements shall be performed both near the surface (approximately 1 cm distance) and at the usual working distance of the trunk (approximately 30 cm). If tools are used, measurements should be performed at the distance appropriate for the use of such tools.

6.5 Determining the transmission factor

Measurements of the transmission factor may be carried out to characterize the shielding effect of protective clothing (see 5.3). For this purpose, the detector is covered with caps of different mass per unit area. For routine tasks, the mass per unit area of the cap should correspond to that of the protective clothing or to the tissue depth of an interesting organ (e.g. 300 mg·cm^{-2} for the lens of the eyes).

The transmission factor T may also be used to estimate the dose rate fraction of weakly penetrating radiation. The transmission factor may be estimated from Figure 2 if the maximum energy for beta radiation is known.

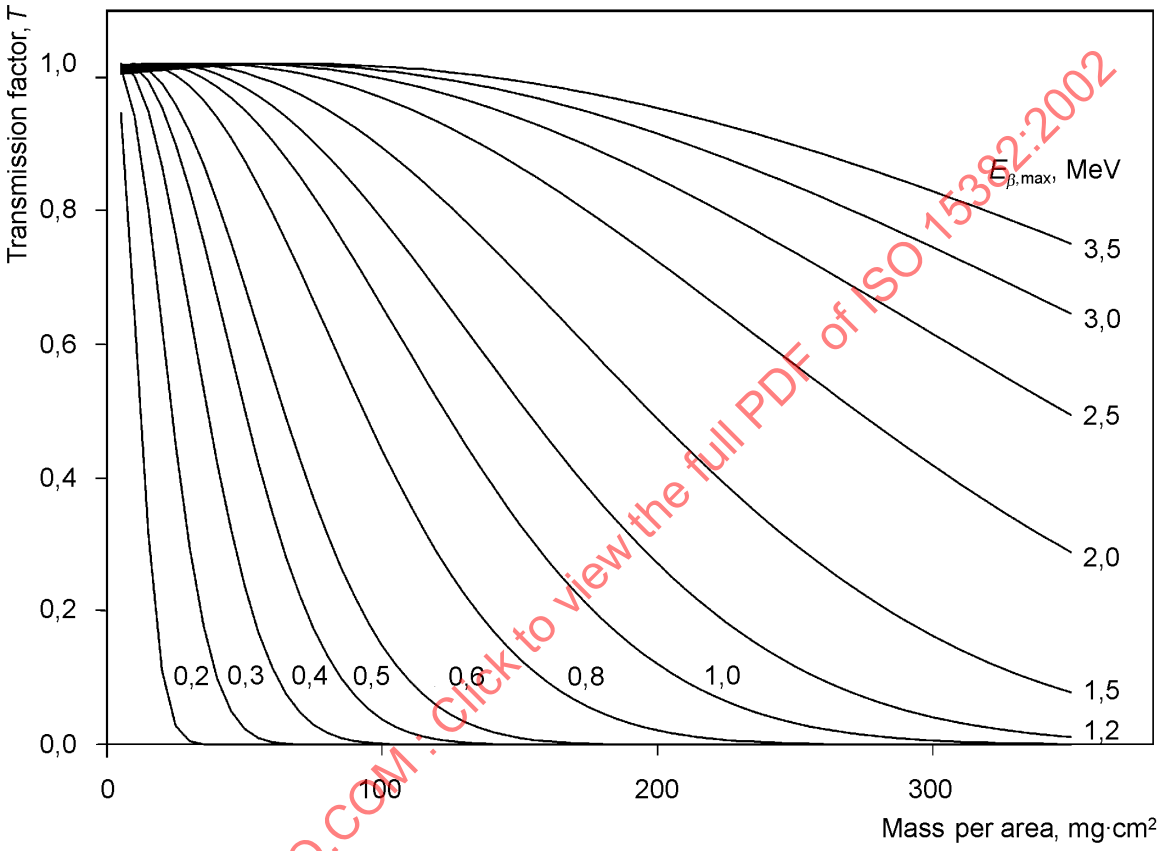


Figure 2 — Approximate values of the transmission factor T for known maximum beta energy as a function of the mass per area, calculated according to equation (3) and Figure 3, both in reference [15]

The curves in Figure 2 depict reference values which overestimate the attenuation by protective clothing if the contamination contains beta emitters of high maximum energy, although their activity fraction is usually small (approximately 2 %). A transmission factor determined from Figure 2 only applies to the attenuation of the dose-rate fraction of weakly penetrating radiation according to 5.2, and not to the dose-rate fraction of strongly penetrating radiation.

NOTE The transmission factor can also be deduced from beta spectral measurements.

6.6 Evaluation of measurement results

On the basis of the measured dose-equivalent rates $\dot{H}'$ (0,07) and $\dot{H}^*$ (10), it is necessary to evaluate whether the work to be carried out:

— involves working close to contaminated surfaces,

— involves sufficient attenuation of the weakly penetrating radiation by protective clothing,

— requires wearing a personal dosimeter measuring weakly penetrating radiation, and/or

— requires additional protective measures.

Such evaluation has to include possible exposures of

— the hands, forearms, feet, lower legs and ankles including the associated skin,

— the other skin regions,

— the testes, and

— the lens of the eyes.

Two cases have to be distinguished in evaluating the attenuation of weakly penetrating radiation by protective clothing:

— the contamination consists almost exclusively of radionuclides emitting beta radiation of low maximum energy (upper limit 320 keV, for examples see annex B);

— all or part of the contamination consists of radionuclides emitting beta radiation of elevated energy ($E_{\beta,\max} > 320$ keV).

In the first case, it is not necessary to determine the dose equivalents caused by weakly penetrating radiation if protective clothing is worn which sufficiently attenuates this radiation.

NOTE Protection of the hands is achieved on the hands by wearing both fabric and rubber gloves with a mass per unit area of 50 mg·cm^{-2} If the trunk is at a distance of more than 30 cm from the radiation source, protective clothing (overalls) with a mass per area of 10 mg·cm^{-2} is sufficient.

In the second case, the partial-body dose to be expected for a person performing a task needs to be estimated on the basis of dose-rate measurements, exposure time and attenuation by protective clothing. The corresponding transmission factor should be determined according to 6.5.

7 Personal dosimetry

7.1 General

A suitable personal dosimeter has to be worn on the extremities if a partial-body dose greater than a nationally fixed value per month (e.g. 1/30 of the annual limit per month) is expected for the hands, forearms, feet, lower legs or ankles including the associated skin, considering all exposures. If a skin dose is expected to exceed the nationally fixed value per month on other parts of the body, a suitable personal dosimeter has to be worn for measuring this skin dose. Partial-body dosimetry for testes and eye lenses is only necessary in exceptional cases.

NOTE 1 The national requirements for the measurement of partial-body dose equivalents are normally given as

a) fixed dose values when the partial-body dose equivalent (or the organ dose equivalent) has to be measured irrespective of the effective dose or the personal dose equivalent measured at the normal position of the approved whole-body dosimeter,

b) ratios between the partial-body dose equivalent (or the organ dose equivalent), or and effective dose, such as when a given ratio is or might be exceeded then the partial-body dose has to be measured, or

c) a combination of a) and b), for example, a fixed value below which partial-body dose equivalents need not be measured and a ratio for when the partial-body dose equivalents has to be measured in case the fixed value is exceeded.

NOTE 2 The partial-body dose to be expected during a month is often difficult to estimate at the beginning of the month. Therefore, partial-body dosimeters are often used regularly at determined workplaces. The need to wear a corresponding dosimeter may arise during the monitoring period.

7.2 Personal dosimetry for hands, forearms, feet, lower legs and ankles including the associated skin

7.2.1 General

Since irradiation of extremities can be very inhomogeneous, it is not appropriate to determine the average dose to the respective extremity, instead the maximum value should be determined.

7.2.2 Measuring requirements

The required annual dose limits, monitoring periods and procedures for assessment of the partial-body dose of hands, forearms, feet, lower legs and ankles, including the associated skin, are given by national regulations.

The requirements for personal monitoring are given by national regulations considering annual dose limits or fractions of it.

A dosimeter shall be worn on the extremity exposed for monthly intervals, if a monthly partial-body dose of more than the nationally fixed value for monitoring is to be expected (see 7.1).

No partial-body dosimeter shall be worn, if the ratio of partial-body dose at the extremity versus effective dose is smaller than the ratio of the prescribed annual nationally fixed value for monitoring (from which on-extremity monitoring is required) versus the annual dose limit of the effective dose, if the annual limit of the effective dose is not exceeded.

7.2.3 Dosimeters

The partial-body dose to the extremities shall be determined using appropriately thin energy-independent dosimeters, e.g. thermoluminescence dosimeters. A dosimeter need not distinguish between weakly and strongly penetrating radiation to the extremities, since the annual limit of the partial-body dose applies to the sum of the doses generated by both types of radiation.

7.2.4 Place of measurement

The partial-body dosimeter should be worn on a finger of the working hand for the region of the hands and forearms, and on the ankle for the region of the feet and lower legs. In exceptional cases, e.g. if working is greatly impaired, the dosimeter may also be worn on an adjacent location (e.g. wrist instead of finger), but then the dose equivalent has to be estimated for that part of the extremity where maximum exposure has occurred.

The dosimeter shall be worn under protective clothing, especially inside gloves, if such clothing is worn. The dosimeter can also be worn outside the protective clothing, but under an equivalent thickness of material. This protects the dosimeter from perspiration, permits easier removal, and gives an accurate measurement of the skin dose.

7.3 Personal dosimetry for the skin

7.3.1 General

Since irradiation of the skin can be very inhomogeneous, it is not appropriate to determine the average dose to the skin, instead the maximum localized skin dose should be determined.

7.3.2 Measuring requirements

The required annual dose limits, monitoring periods and procedures for assessment of the partial-body dose for the skin of parts of the body other than those specified in 7.2 are given in national regulations.

No such dosimeter need be worn, if the ratio of directional dose-equivalent rate, $\dot{H}'(0,07)$, (possibly under protective clothing) to ambient dose-equivalent rate, $\dot{H}^*(10)$, is smaller than the ratio of the corresponding dose equivalent limits, since in that case the skin dose limit cannot be exceeded without exceeding the effective dose limit.

7.3.3 Dosimeters

The personal dose equivalent to the skin shall be determined using thin tissue-equivalent dosimeters, e.g. thermoluminescence dosimeters.

A dosimeter worn on the trunk need not necessarily indicate low-energy beta radiation (source energy $E_{\beta,\max} < 320$ keV), since this type of radiation is considerably attenuated by the air between the radiation source and dosimeter (Figure 2). If the maximum β-energy of the source is lower than 320 keV and the distance of the source and the trunk is larger than 30 cm, the dose to the skin need not be measured at the trunk, since low energy β-radiation is considerably attenuated by the air between the radiation source and the dosimeter.

NOTE Geiger-Müller detectors are not suitable for detecting weakly penetrating radiation. Special radiophotoluminescent (RPL) dosimeters (phosphate glass dosimeters) and special silicon detector dosimeters can be applicable. The film dosimeter can detect high-energy beta radiation, but from the optical density, high-energy beta radiation cannot be discriminated against low-energy gamma radiation, while both radiation types will need different calibration factors.

7.3.4 Place of measurement

In selecting the representative measurement position for the partial-body dosimeter to determine the localized skin dose, the attenuation by protective clothing has to be specifically taken into account in addition to the distance from the radiation source.

If weakly penetrating radiation is only slightly attenuated by protective clothing, the localized skin dose may also be determined at the location of the whole-body dosimeter worn on the clothing.

In the case of effective attenuation by protective clothing, unprotected skin regions, e.g. on the head, may be more exposed than the skin on the trunk; in that case, the localized skin dose needs to be determined at the unprotected location or at an equally exposed location.

NOTE For practical reasons, it may be appropriate to wear the dosimeter on the trunk outside protective clothing instead of wearing it, for instance, on the head.

7.4 Personal dosimetry for the testes

7.4.1 Measuring requirements

The annual limit and the required monitoring for the partial-body dose of the testes can be found in national regulations. Due to the small contribution of beta radiation to the testes dose, a determination is only required, if the maximum β-radiation energy is above 1 MeV and the skin dose near the testes reaches the annual limit (see [15] in the bibliography).

NOTE 1 β^--radiation with energies greater than 1 MeV can contribute to the testes dose. Conversion electrons and β^+-radiation behave approximately like β^- radiation. In most cases, the contribution of this radiation to the testes dose is small. For beta radiation from ^{124}Sb, for example, the testes dose equals about 1 % of the skin dose, including the attenuation by air and protective clothing, and it is low compared with the contribution to the testes dose generated by simultaneously existing strongly penetrating radiation.

Low-energy photon radiation is generally accompanied by photon radiation of higher energy. Therefore, a determination of the testes dose for photons with energies below 15 keV is only required in exceptional cases.

NOTE 2 For photons with energies below 15 keV, the ratio between testes dose and directional dose equivalent, $H'(0,07)$, is smaller than 0,05 (see [15] in the bibliography).

7.4.2 Dosimeters

The testes dose shall be determined using thin tissue-equivalent dosimeters covered by a tissue-equivalent layer of a thickness corresponding to the effective depth of the testes. The partial-body dose of the testes should be determined using appropriately thin tissue-equivalent dosimeters, e.g. thermoluminescent dosimeters.

For extended organs, e.g. testes, the dose shall be averaged over the whole organ. This average value is equal to the dose at a particular tissue depth, the effective depth.

The effective depth depends on the energy of beta radiation. It ranges from 2 mm to 9 mm for beta radiation with energies greater than 1 MeV (see [16] in the bibliography).

7.4.3 Place of measurement

The partial-body dosimeter should be worn in close proximity to the testes.

In selecting the representative measurement position for the partial-body dosimeter to determine the equivalent dose to the testes, the attenuation by protective clothing shall be specifically taken into account in addition to the distance from the radiation source. The dosimeter shall be covered by material with thickness equivalent to the protective clothing.

7.5 Personal dosimetry for the lens of the eye

7.5.1 Measuring requirements

The annual limit and the required monitoring for the partial-body dose of the lens of the eyes can be found from national regulations.

A determination of the partial-body dose for the lens of the eyes is only required in exceptional cases for beta radiation with $E_{\beta,\max} > 3{,}5$ MeV. A tissue depth of 3 mm is estimated for the lens of the eyes.

For beta radiation with maximum energies $E_{\beta,\max} < 3{,}5$ MeV (ICRU 43[17]) and for photons with energies $E_{ph} < 10$ keV, the ratio of dose equivalent on the skin surface to that at 3 mm depth is greater than 3,3, i.e. greater than the ratio of the annual limits recommended by ICRP for skin and the lens of the eyes. In these cases, the dose on the skin determines the limit. A partial-body dose determination for the lens of the eyes is therefore not required for the radiation specified above if the skin dose near the eyes does not exceed the dose limit.

A dose determination for eye lenses is also not required if respirators with sight glasses which absorb weakly penetrating radiation almost completely are worn.

7.5.2 Dosimeters

The partial-body dose to the lens of the eyes shall be determined using tissue-equivalent dosimeters covered by a tissue-equivalent layer of 300 mg·cm^{-2}.

7.5.3 Place of measurement

The partial-body dosimeter should be worn on the forehead in close proximity to the eyes.

In selecting the representative measurement position for the partial-body dosimeter to determine the equivalent dose to the lens of the eye, the attenuation by protective material, for example, face mask and glasses has to be specifically taken into account in addition to the distance from the radiation source.

8 Special cases

8.1 Radioactive noble gases

The directional dose-equivalent rate, $\dot{H}'(0,07)$, caused by radioactive noble gases in room air is to be calculated, if necessary, from the radionuclide composition and "concentration" (expressed in terms of activity per volume unit, or derived air concentration, DAC) or should be determined by a measurement of the directional dose-equivalent rate (thin thermoluminescent dosimeters; thin walled ionization chamber). If relevant, the skin dose should be calculated from the results taking the exposure period into consideration.

The directional dose-equivalent rate due to beta radiation in contaminated air with locally constant activity concentration as a function of the maximum energy of the radionuclide according to [18] and [19] in the bibliography is shown in Figure 3.

NOTE 1 If the room dimensions are smaller than double the range in air for beta radiation, the directional dose-equivalent rate is smaller than the value estimated according to Figure 3.

NOTE 2 Previous experience in nuclear power plants has shown that the dose rate due to radioactive noble gases in room air is so low that, in general, it need not be taken into consideration.

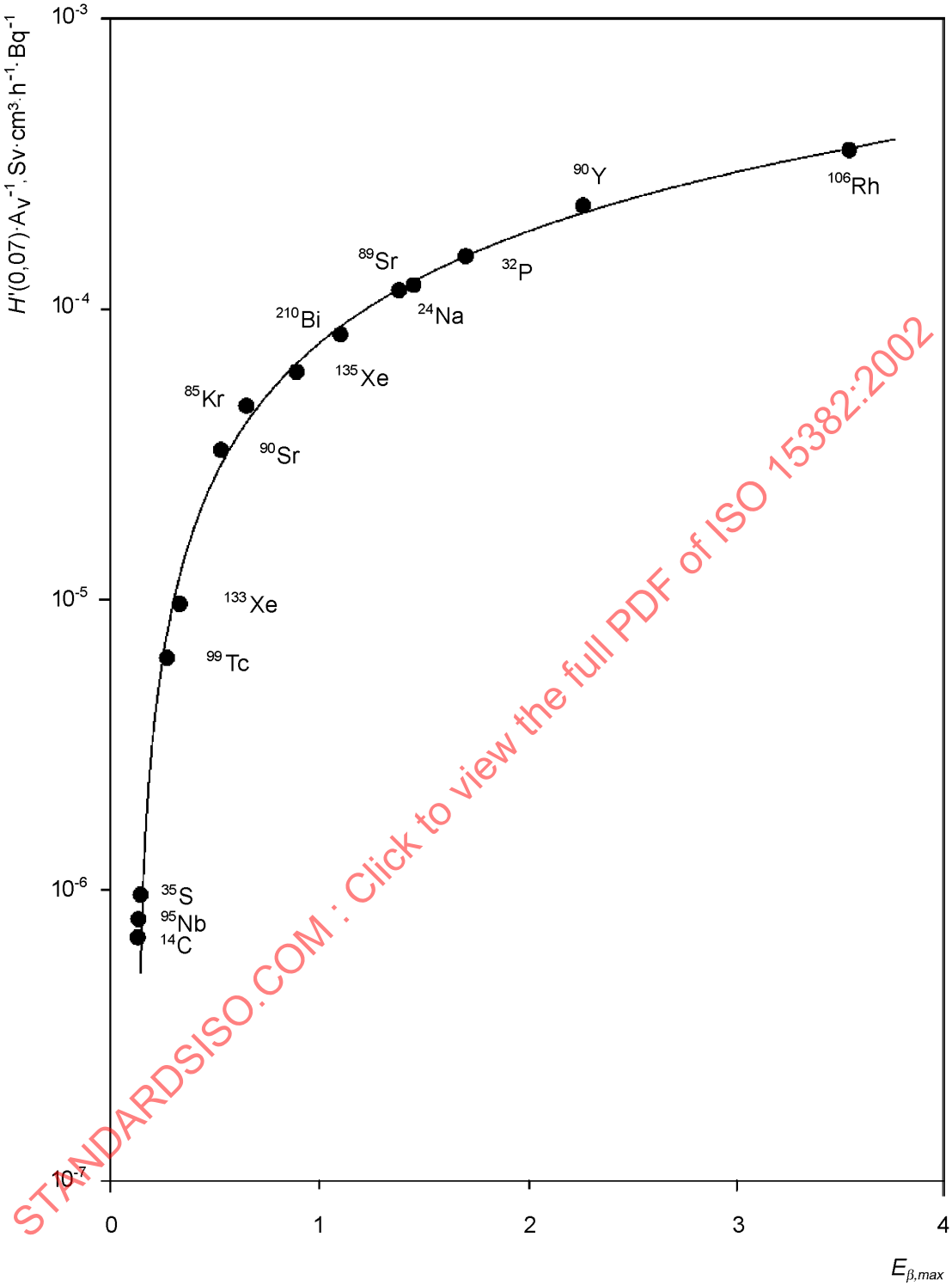


Figure 3 — Directional dose-equivalent rate $\dot{H}'$ (0,07) due to beta radiation divided by the activity per unit volume, A_V, for homogeneously contamined air as a function of $E_{\beta,\max}$ (see [18] and [19] in the bibliography)

8.2 Skin contamination

8.2.1 General

In cases of skin contamination with radioactive substances, immediate and rapid decontamination measures are of higher priority than an exact evaluation of skin activity and dose. Exact evaluations of skin activity and dose are recommended only in such cases where skin contaminations cannot be removed by decontamination procedures, and the skin dose is expected to exceed the given limit (see 8.2.2).

For skin contaminations, the skin dose is generated mainly by weakly penetrating radiation, especially beta radiation. The dose component resulting from beta radiation is, in general, substantially higher than the one induced by photons. In exceptional cases, high-energy alpha radiation, with particle energies of $E > 6$ MeV and particle ranges above the thickness of the epidermis, can also contribute to the skin dose.

8.2.2 Necessity for skin dose assessment

The annual limit for the localized skin dose is given in national regulations. A skin dose evaluation is recommended as a precaution in cases where a high localized skin dose is expected, e.g. 1/10 of the annual limit per month.

NOTE In the case of contamination of hands, forearms, feet, lower legs and ankles, the annual limit recommended in ICRP 60[20] is 500 mSv for category A workers averaged over any 1 cm^2, and correspondingly 50 $mSv \cdot month^{-1}$, regardless of the area exposed.

EXAMPLE A Skin dose of $H_p(0,07)$ = 50 mSv due to contamination of the skin with high-energy beta emitters, e.g. ^{32}P, ^{90}Y, is generated by an activity per unit area, A_F, of A_F = 31 $kBq \cdot cm^{-2}$ in 1 h or by A_F = 1,3 $kBq \cdot cm^{-2}$ in 24 h.

8.2.3 Assessment of skin dose

For skin dose assessment in cases of skin contamination, the amount of activity on the skin, the area of the contaminated skin, and the duration of skin contamination should be determined, apart from the composition of radionuclides involved. Since contaminations are usually distributed unhomogeneously on the skin, and since for monitoring the dose limits of the skin the highest value of the local skin dose is considered, the activity, A, and correlated skin area, F, should be determined at the place of maximum contamination. For contaminated skin areas < 1 cm^2, the activity per area, $A_F = A \cdot F^{-1}$, is averaged over an area of 1 cm^2.

In the case of contaminations of the skin surface, the skin dose, H_{skin}, is calculated using the formula:

$$H_{skin} = A_{F,O} \cdot I_C \cdot \lambda^{-1} \cdot \left(1 - e^{-\lambda t}\right) \quad (3)$$

where

$A_{F,O}$ is the activity per unit area at the beginning of contamination;

I_C localized skin dose rate factor;

λ decay constant, $\lambda = \ln 2 / T_{1/2}$ ($T_{1/2}$ is the physical half-life of the radionuclide or radionuclide composition);

t duration of skin contamination.

If the activity per unit area, A_F, is given in $Bq \cdot cm^{-2}$, both the physical half-life, $T_{1/2}$, and the duration of contamination, t, in hours, and the equivalent dose-rate factor, I_C, is given in $Bq^{-1} \cdot \mu Sv \cdot h^{-1} \cdot cm^2$, then the skin dose, H_{skin} is determined in µSv.

Usually $T_{1/2} >> t$ and hence there is no need to consider the decrease of contamination by radioactive decay, the above formula is reduced to:

$$H_{\text{skin}} = A_{\text{F,O}} \cdot I_{\text{C}} \cdot t \tag{4}$$

The equivalent dose rate factor, I_{C}, is equal to:

$$I_{\text{C}} = \sum_i I_{\text{C},i} \tag{5}$$

where $I_{\text{C},i}$ is the contribution of radiation type i (alpha, beta or photon radiation) to the equivalent dose-rate factor. In the case of beta emitters, the contributions $I_{\text{C},i}$ are given in [21] and [22] in the bibliography, for photons in [23] and for alpha radiation in [24], for many radionuclides. Equivalent dose-rate factors, I_{C}, for some more frequently occurring radionuclides are compiled in informative annex C.

NOTE For skin contaminations delivering low-penetration radiation the skin dose, H_{skin}, as an approximation does not depend on the extension of the contaminated area, F. As a consequence, the activity per area, $A_{\text{F}} = A \cdot F^{-1}$, is averaged over an area of 1 cm^2.

In the case where activity has penetrated the skin, special calculations shall be performed. Guidance should be sought in the literature, e.g. ICRU 56[2].

In the case of unidentified radionuclides, the skin dose can be estimated using the measured surface emission rate to calculate $A_{\text{F,O}}$ and the skin-dose-rate factor for high-energy beta emitters, I_{C} = 1,6 μSv·h^{-1}·Bq^{-1}·cm^2.

8.2.4 Hot particles

Hot particles are small radioactive sources which can deliver highly non-uniform, localized dose distributions when in contact with the skin. These arise in connection with power reactor operations in the form of metallic particles containing neutron activation or fission products. The biological effects of hot particles on the skin have been considered in detail in ICRP 59[25]. ICRP 59 advises that the dose threshold for unacceptable acute effects, such as ulceration, is 1 Sv averaged over an area of 1 cm^2 at a depth of 100 μm to 150 μm.

The general recommendations subsequently given by ICRP 60[20] for a skin dose limit (500 mSv over 1 cm^2 at 0,07 mm) are thus somewhat conservative for a hot particle exposure. A hot particle exposure in the working environment is unlikely to be recorded by a personal dosimeter but should be detected by the routine use of exit monitors or contamination monitors.

In the event of the recording of localized radioactive contamination of the skin or clothing, every effort should be made to retrieve the activity for subsequent investigation. It is important to record details of the exposure such as body site, clothing/shielding, likely duration of exposure, etc.

The dose to 1 cm^2 of skin at a depth of 0,07 mm may be evaluated by direct measurement using techniques such as thermoluminescence dosimetry, extrapolation ionization chamber, exo-electron dosimetry (see [26] in the bibliography) or radiochromic dye films (ICRP 56[2]). Calculations of skin dose may also be made using tabulated beta dose distributions (ICRP 56[2]) or PC-based codes (e.g. VARSKIN, Monte Carlo codes) but this requires information on the particle characteristics, composition and activity (usually obtained by gamma ray spectrometry and supplemented by some assumptions regarding the presence of pure beta emitters).

The hot particle dose limit applies to a single exposure from one particle. The ICRP have not provided guidance on the effects or dose limits for exposure from a number of particles either sequentially or simultaneously.

The evaluation of hot particle doses provides an indication of the acceptability of contamination levels. The information may need to be formally recorded, depending on local rules or national regulations.

9 Assessment of partial-body doses

9.1 Equating partial-body dose and personal dose equivalent

The personal dose equivalent measured with a partial-body dosimeter should be compared with the investigation levels in national regulations (see informative annex A). If the personal dose equivalent measured on a part of the body is below or equal to the associated investigation level, then the personal dose equivalent may be equated to the partial-body dose. If the personal dose equivalent exceeds the investigation level, then it should be considered whether partial-body dose limits are exceeded (see 9.2).

9.2 Calculating the partial-body dose

The partial-body dose should be calculated if there is reason to assume, for example, on the basis of personal dose equivalent measurements, that dose limits may be exceeded. This is the case if

— the investigation level is exceeded;

— the personal dose equivalent summarized over a calendar year exceeds the annual dose limit applicable to the particular part of the body concerned; or

— it is doubtful whether the measured value of the partial-body dose exceeding the investigation level is representative for the actual exposure and measurement conditions of the person monitored.

The measurement value is considered to be representative if

— errors in indication (e.g. due to instrument failure) or exposure conditions (e.g. due to a dosimeter not worn on the body) are either irrelevant or taken into account, and

— it can be estimated on account of the exposure conditions (e.g. dosimeter worn at the location of maximum dose and high-energy beta radiation) that the associated partial-body dose is not higher than the measured personal dose equivalent. Any measurement deviations due to the energy and directional dependence of dosimeter response should be taken into account.

Calculation procedures for the partial-body dose are subject to national regulations, e.g. [15] in the bibliography.

10 Documentation of partial-body doses

The partial-body doses determined by personal dose monitoring on parts of the body have to be documented according to national regulations and monitored with respect to the dose limits.

The partial-body doses are determined by:

— equating the partial-body dose with the personal dose equivalent (according to 9.1);

— calculating the personal dose equivalent (according to 9.2);

— calculation from the air activity concentration (according to 8.1) or skin contamination (according to 8.2); or

— extrapolation to the location of maximum exposure (according to 7.2.4).

For monitoring dose limits the partial-body doses determined for different monitoring periods shall be summed-up.

In many cases, the period in which the partial-body dose is determined is different from the one in which the whole-body dosimeter was worn. This shall to be taken into account when summing-up the doses.

If the partial-body dose was not explicitly determined for a complete monitoring period, then the personal dose equivalent $H_p(10)$ obtained with the approved whole-body dosimeter is also regarded as the partial-body dose H_T, for the period during which the partial-body dosimeter was not worn:

$$H_p(10) = H_T \quad (6)$$

NOTE If the period for which the partial-body dose was determined, in general the period during which the partial-body dosimeter was worn, is shorter than the period of monitoring with the approved whole-body dosimeter, then the partial-body dose, H_T, for this longer period is the sum of the partial-body dose, H_t, determined for the shorter period, and the personal dose equivalent, $H_p(10)$, determined with the approved whole-body dosimeter for the longer period, $H_T = H_t + H_p(10)$, tolerating an overestimation.

In exceptional cases, this rough estimate can indicate that the dose limit for the partial-body dose is exceeded. In these cases, the partial-body dose should be estimated more precisely.

If a person wears several partial-body dosimeters at different times on the same part of the body during a monitoring period together with the approved whole-body dosimeter, in general one month, it will be sufficient to document the individual dose values in operational records. The individual values should be summed-up to monthly values and documented.

After completion of a work in a facility different from his home facility, the holder of a radiation passport, if applicable due to national regulations, shall have his/her personal dose recorded in this document. If a dose equivalent according to clause 9 is to be determined, it will first of all be sufficient to document the measured value or the measured value extrapolated according to 7.2.4.