Calculation Guide Mining

Calculation Guide for the Determination of Radiation Exposure due to Environmental Radioactivity Resulting from Mining

Department
Radiation Protection and Environment

Bundesamt für Strahlenschutz

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PREFACE TO THE GERMAN EDITION

The present “Calculation Guide Mining” (Berechnungsgrundlagen Bergbau) is the result of a revision and summarization of the “Calculation Guide for the Determination of Radiation Exposure due to Mining-caused Environmental Radioactivity” (Berechnungsgrundlagen zur Ermittlung der Strahlenexposition infolge bergbaubedingter Umweltradioaktivität)” and the "Calculation Guide for the Determination of Radiation Exposure due to Inhalation of Radon and its Short-lived Decay Products as a Result of Mining-caused Environmental Radioactivity" (Berechnungsgrundlagen zur Ermittlung der Strahlenexposition durch Inhalation von Radon und seinen kurzlebigen Zerfallsprodukten infolge bergbaubedingter Umweltradioaktivität) which had been effective separately up to now.

Both documents were prepared in the mid-nineties by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) in cooperation with the Federal Office for Radiation Protection (BfS) involving external experts (Brenk Systemplanung and the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)), discussed in the Commission on Radiological Protection (SSK)[1], and forwarded to the Laender of Saxony, Saxony-Anhalt, and Thuringia by the BMU in 1999. In these Laender, the Calculation Guide is applied for the purpose of testing in practical implementation, especially in remediation projects of the Wismut GmbH.

Both Calculation Guides were widespread during the last decade and have established themselves successfully in the assessment of radiation exposure from environmental radioactivity due to mining since their publication. This is essentially due to the fact that these documents were the first to specify calculation models and parameters enabling a “realistic, but sufficiently conservative” assessment of intervention situations in radiological protection according to the SSK.

Nevertheless the experience gained during the last ten years of application of the Calculation Guides, as well as more recent research results necessitated a revision. This was done with particular consideration of indications made by the above Federal Laender and the Wismut GmbH as well as by experts. The summarized and modified Calculation Guide Mining has been discussed at length in the SSK-committees and was passed in 2009 in the 235 meeting of the SSK.

The Calculation Guide Mining is confined to specifying procedures to calculate radiation exposure due to mining. It does not contain material radiation protection requirements such as regulations concerning remediation objectives or information as to the prerequisites for the justification of remediation operations.

[1] The SSK did not discuss the "Calculation Guide for the Determination of Radiation Exposure due to Inhalation of Radon and its Short-lived Decay Products as a Result of Mining-caused Environmental Radioactivity" (Berechnungsgrundlagen zur Ermittlung der Strahlenexposition durch Inhalation von Radon und seinen kurzlebigen Zerfallsprodukten infolge bergbaubedingter Umweltradioaktivität") at that time because it had passed an appropriate recommendation in 1995.

PREFACE TO THE ENGLISH EDITION

In recent years, BfS has repeatedly been asked to make the Calculation Guide available to professionals abroad, among others in connection with the European ALARA – NORM Network. There were different reasons for these requests, such as the intention to facilitate comparison with other countries' guidelines and dose estimates or possible future harmonization, or to adopt at least parts of it in countries where no such guides exist.

BfS compiled this English edition to meet these requests. However, it is important to note that a variety of models and parameters used in this guide are specific to the conditions in Germany, for reasons of specific natural conditions or the existing legal framework. Examples are the natural background levels, or consumption rates for food. Therefore, the applicability of the guide should be checked carefully prior to its use in other countries.

ABSTRACT

The present “Calculation Guide Mining” serves to determine mining-caused radiation exposure of members of the public and of workers. It is applicable for the use, decommissioning, remediation, and reuse of mining plants and installations as well as for the use, remediation, and reuse of land contaminated as a result of mining plants and installations.

The “Calculation Guide Mining” describes procedures and parameters to determine effective dose indoors, at underground workplaces, and outdoors, as well as for consumption of breast milk and locally produced foodstuff. The following exposure pathways are considered: external exposure due to gamma-radiation from the soil, exposure due to inhalation of dust, exposure due to inhalation of radon and its short-lived decay products, exposure from ingestion of breast milk and locally produced foodstuff (drinking water, fish, milk and milk products, meat and meat products, leafy vegetables, other vegetable products), and exposure due to direct soil ingestion.

In order to account for the natural level of environmental radioactivity involved in measurements, the “Calculation Guide Mining” includes levels of natural background for all relevant environmental media.

CONTENTS

PART I GENERAL PRINCIPLES

1 Scope

The present Calculation Guide is applicable for the assessment of radiation exposure of humans[1)] in intervention situations due to mining residues (radiation exposure from mining), particularly in the following applications:

- use, decommissioning[2)], remediation[2)] und reuse[3)] of mining installations and facilities[3)],
- use, remediation[2)] and reuse of other estates contaminated[4)] as a result of mining installations and facilities[5)].

The Calculation Guide is not applicable for underground facilities and equipment, except for the assessment of radiation exposure due to radon and its short-lived decay products. Furthermore, the Calculation Guide is not valid for use and reuse of contaminated mining materials such as mine dump materials used as building additive.

The Calculation Guide applies for providing evidence of compliance with dose limits for workers and dose constraints for members of the public, for estimating exposure from mining residues, and for the planning and optimization of measures reducing exposure.

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[1] The Calculation Guide is not applicable for assessment of collective dose.

[2] Except for installations or plant locations of which decommissioning or remediation are subject to licensing under the Atomic Energy Act.

[3] Reuse means use after remediation or restriction on use.

[4] Contamination here and in the following means pollution by radioactive substances.

[5] For radioactive contaminations caused or influenced by chemical tailings, special exposure pathways and parameters have to be accounted for when calculating the mining-caused radiation exposure if necessary (see also Part I, Para. 2.2).

2 Aims and principles of determining radiation exposure

2.1 Objectives

The Calculation Guide serves to assess human radiation exposure from mining.

2.2 Principles of application

From the exposure scenarios and pathways itemized in Part I, Para 2.5 only those relevant in the precise application shall be accounted for when applying the Calculation Guide. The exposure scenarios and pathways, calculation parameters and radionuclides to be considered when assessing radiation exposure from mining have to be selected preferentially on the basis of qualitative estimates. Cases of doubt shall be clarified by means of deepening examinations of the site and exposure conditions.

When the ground water in the downstream of a mining residue is able to be used for drinking water abstraction by domestic wells, ground water usage has to be assumed in either case notwithstanding Part I, Para 2.2 first sentence if concern about ground water contamination cannot be excluded. The operation of domestic wells requires among others an appropriate depth to the water table, sufficiently usable ground water availability and suitable ground water quality with regard to its geogenic, chemical and biological properties. Taking account of the radiation exposure via the ground water pathway is not required, when the establishment of domestic wells can be excluded by determinations under planning law or due to the nature of the area, taking into account the expected development (see Part I, Para 2.3.2) or in cases of a permanent man-made high pollution load of the ground water due to which the use as drinking water is excluded by virtue of regulatory measures in the long run.

Besides the exposure pathways described in the Calculation Guide, additional exposure pathways have to be accounted for in exceptional cases where this is justified by specifics of application, site or mining residues. The same applies for the calculation parameters and radionuclides.

2.3 Reference persons and receiving points

Radiation exposure must be assessed for reference persons at the most unfavourable receiving points.

2.3.1 Reference persons

a) Reference persons are members of the public and workers for whom specific calculation parameters (dose coefficients, dose conversion coefficients, breathing rates, exposure sites, exposure times and types of ingestion and uptake) are given in the Annexes.

b) „Workers“ are individuals occupationally concerned with the decommissioning or remediation of mining residues, if these occupational activities or practices are subject to monitoring. To calculate the radiation exposure of the reference person „worker“ it is necessary to specify the exposure scenarios, exposure pathways, radionuclides and calculation parameters to be considered by reason of the occupational activity or practice. These occupational activities or practices that may be carried out at underground workplaces as well as inside plant buildings or on plant areas outdoors are assumed to amount to a total of 2000 hours per year at most (see Annex I, Table I.2). The radiation exposure incurred by a "worker" beyond their ccupational activity or practice is not accounted for when calculcating radiation exposure from mining. When assessing effective dose for the reference person "worker" from measured values the contribution made by natural ambient radioactivity need not be subtracted.

c) Individuals occupationally concerned with practices or activities related to mining residues whithout being subject to monitoring are assigned to the reference person "adult" ("> 17 a“).These occupational activities or practices are assumed to amount to a total of 2000 hours per year at most. For these individuals, additional exposures during leisure shall only be accounted for when exposure times indoors and outdoors as specified in Annex I, Table I.2. have been exhausted by occupational activities or practices.

2.3.2 Receiving points

a) Receiving points are the locations of, or in the vicinity of mining facilities or equipment where reference persons may stay or where food may be produced covering the proportion specified in Part I, Para 2.6.4 of the annual consumption by reference persons according to Annex IV, Table IV. 2.

Locations with a mean annual concentration of up to 5 Bq m^{-3} of mining-caused ^{222}Rn are not considered as receiving points (exemption criterion). Accordingly, times spent at such locations shall not be accounted for when assessing mining-caused radiation exposure from ^{222}Rn and its short-lived decay products.

b) Unfavourable receiving points are those where the highest radiation exposure of the reference person is expected for the exposure scenarios and pathways to be considered, accounting for realistic uses and behaviour. The most unfavourable receiving points shall be determined in the precise application, and up-to-date uses and/or potential future uses shall be comprised, depending on the area and case of application.

c) Determinations under planning law as well as the nature of the area, taking into account the expected developent, shall be observed when determining potential future uses, taking account of its conceivable development. If uses are prohibited by regulatory provisions (e.g. restriction on use) or due to measures taken by the owner of the mining residue (e.g. access control), these uses remain out of consideration when assessing radiation exposure. The same applies for uses that may be excluded by reason of ecologic conditions at the site or time limitation to the application.

2.4 Evaluation criteria

Radiation exposure from mining is usually calculated in terms of effective dose per year. As far as legally allowed and appropriate for the respective application, the radionuclide concentration or local dose rate determined for individual exposure pathways and radionuclides may be evaluated by other means than calculating effective annual dose when the appropriate radiological criteria are applied.

2.5 Exposure scenarios and pathways

The Calculation Guide accounts for the following exposure scenarios:

- indoors (dwellings and public buildings[1)], commercial buildings),
- underground workplaces (only inhalation of radon[2)] and its short-lived decay products),
- outdoors,
- ingestion of breast milk and locally produced food (vegetable and animal products, as well as water),

and the following exposure pathways:

- external exposure to gamma radiation from soil,
- exposure from inhalation of dust,
- exposure from inhalation of radon and its short-lived decay products,
- exposure from ingestion of breast milk and locally produced food (drinking water, fish, milk and milk products, meat and meat products, leafy vegetables and other vegetable products), as well as
- exposure from direct soil ingestion.

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[1] „public buildings“ is understood as a general term for all types of buildings (e.g. schools, nursery schools, sports halls) that might be used by the general public.
[2] In the following “radon” represents ^{220}Rn and ^{222}Rn.

2.6 Requirements to be met when assessing radiation exposure

The following requirements shall be observed when using the Calculation Guide:

2.6.1 Exposure scenario „indoors“

a) When the indoors exposure scenario (commercial buildings) is considered, the times assumed to be spent indoors by workers must be realistic. Part I, Para 2.3.1 b) shall be observed.

b) When calculating radiation exposure of reference persons from the general public, a maximum time of 7000 hours per year shall be assumed to be spent indoors (residential buildings) as a general rule. However, staying indoors does not necessarily mean to spend time exclusively within a building situated at the “most unfavourable receiving point”.

c) As a general rule, the indoors exposure scenario requires that the exposure pathways “external exposure to gamma radiation from soil”, “inhalation of dust” and “inhalation of radon and its short-lived decay products” be accounted for. These pathways are relevant according to Part I, Para 2.2, when the buildings are situated

- on, or at immediate proximity to mining installations and facilities (up to a distance of 20 m) as for the pathway „external exposure to gamma radiation from soil“,
- on, or in the vicinity of mining installations and facilities (up to a distance of 100 m), as for the pathway „inhalation of dust“, and
- on, or in the vicinity of mining installations and facilities, as for the pathway „inhalation of radon and its short-lived decay products“. Part I, Para 2.6.1 d) shall be observed.

d) When assessing the ^{222}Rn concentration in ambient air (inhaled air) for the reference person of the general public, allowance must be made for:

- inflow of ^{222}Rn-containing soil air from the building foundation, as far as the building is situated on, or at immediate proximity of, a mining installation or facility (as far as this pathway might be relevant according to Part I, Para 2.2, its contribution shall be assessed based on site-specific examinations in the particular case),
- inflow of ^{222}Rn-containing external air, if the building is situated at, or in the vicinity of, a mining installation or facility. Part I, Para 2.3.2 a) shall be observed.

e) External radiation exposure and radiation exposure from inflow of contaminated external air into the building is calculated based on measured values or via air dispersion calculations for an outdoor receptor point adjacent to the building. Part I, Para 2.6.7 shall be observed. The shielding effect of the building has been accounted for in the calculation provisions (Part II, Paras 1 and 2).

The value determined for outdoors shall be assumed when calculating the ^{222}Rn concentration in indoor air. The values indicated in Annex III, Table III.2 are applicable for the equilibrium factor.

2.6.2 Exposure scenario „underground workplaces“

The exposure scenario „underground workplaces“ requires radiation exposure calculation based on workplace-related examinations.

2.6.3 Exposure scenario „outdoors“

a) The outdoors exposure scenario requires realistic assumptions of times spent outdoors by workers. Part I, Para 2.3.1 b) shall be observed.

b) When calculating radiation exposure for reference persons of the general public, the time spent outdoors shall be assumed to reach a maximum of 2000 h per year as a general rule. However, staying outdoors does not necessarily mean spending time exclusively on a site located at the "most unfavourable receiving point".

c) The outdoor scenario basically requires that the exposure pathways „external exposure to gamma radiation from soil“, „dust inhalation“, „inhalation of radon and its short-lived decay products“ as well as „direct soil ingestion“ be accounted for. These pathways are relevant according to Part I, Para 2.2, if sites of exposure of reference persons are situated

- on, or at immediate proximity to mining installations and facilities (up to a distance of 20 m) as for the pathway „external exposure to gamma radiation from soil“,
- on, or in the vicinity of mining installations and facilities (up to a distance of 100 m), as for the pathway „inhalation of dust“,
- on, or in the vicinity of mining installations and facilities, as for the pathway „inhalation of radon and its short-lived decay products“ (Part I, Para 2.6.1 d) shall be observed) and
- on mining installations and facilities as for the pathway "direct soil ingestion".

d) The data in Annex III, Tab. III.2 are applicable for the equilibrium factor of mining-caused ^{222}Rn when the assessment of radiation exposure is based on measured values of ^{222}Rn concentrations or conservative estimates according to Annex VI.

2.6.4 Exposure scenario „ingestion of locally produced food“

a) For the exposure scenario „ingestion of locally produced food“ it shall be generally assumed that only 50 per cent of the annual consumption of agricultural products as specified in Annex IV, Table IV. 2 (fish, milk and dairy products, meat and meat products, leafy vegetables, other vegetable products) is covered by foodstuffs contaminated by the mining residues (proportion of local production). Regarding cereals, the proportion of local products consumed is assumed to be negligible. Drinking water is assumed to be completely contaminated by mining residues unless special circumstances (e.g. distant water supply) justify the assumption of a lower proportion of locally drinking water supply.

b) As a general rule, the following exposure pathways shall be accounted for with the scenario „ingestion of locally produced food“:

- transfer from soil to plant

  soil - plant
  soil - plant - breast milk
  soil - forage plant - cow - milk
  soil - forage plant - cow - milk - breast milk
  soil - forage plant - animal - meat
  soil - forage plant - animal - meat -breast milk

- release with air

  air - plant
  air - breast milk
  air - plant - breast milk
  air - forage plant - cow - milk
  air - forage plant - cow - milk - breast milk
  air - forage plant - animal - meat
  air - forage plant - animal - meat - breast milk

- release with water

  drinking water
  drinking water - breast milk
  water - fish
  water - fish - breast milk
  spray irrigation - plant
  spray irrigation - plant - breast milk
  spray irrigation - forage plant - cow - milk
  spray irrigation - forage plant - cow - milk - breast milk

spray irrigation - forage plant - animal - meat
spray irrigation - forage plant - animal - meat - breast milk
cattle watering trough - cow - milk
cattle watering trough - cow - milk - breast milk
cattle watering trough - animal - meat
cattle watering trough - animal - meat - breast milk

Unless noted otherwise, these exposure pathways are relevant according to Part I, Para 2.2 in the following conditions:

- contamination pathway „transfer from soil to plant" if plants are grown on mining installations or facilities,
- contamination pathway „release with air", if plants are grown on, or in the vicinity of, mining installations and facilities (up to a distance of 100 m),
- contamination pathway „release with water", if groundwater contamination is possible or a surface water exhibits average flow rates of at least 50 L s^{-1}. These restrictions and the following restrictions for surface waters are only applicable in the absence of water retention:

- Only the sub-pathways „spray irrigation - plant", „spray irrigation - plant - breast milk", „cattle watering trough - cow - milk", „cattle watering trough - cow - milk - breast milk", „cattle watering trough - animal - meat" and „cattle watering trough - animal - meat - breast milk" are relevant for average flow rates between 50 L s^{-1} and 500 L s^{-1}.
- In addition, the sub-pathways „spray irrigation - forage plant - cow - milk", „spray irrigation - forage plant - cow - milk - breast milk", „spray irrigation - forage plant - animal - meat" and „spray irrigation - forage plant - animal - meat - breast milk" are relevant for average flow rates between 500 L s^{-1} and 5000 L s^{-1}.
- Additionally, the sub-pathways „drinking water", „drinking water - breast milk", „water - fish" and „water - fish - breast milk" are relevant for average flow rates above 5000 L s^{-1}.

c) When calculating radiation exposure, the contamination pathways „transfer from soil to plant" and „release with air" shall only be considered if the mining installations or facilities, or the area contaminated due to release with air, respectively, are large enough and apt to enable the above-mentioned proportion of local production for reference persons of the general public. This applies accordingly to the pathways „release with water" concerning the availability and suitability of waters contaminated as a result of mining. Sub-pathways, for which this condition is not fulfilled, are deemed to be irrelevant according to Part I, Para 2.2.

d) In case of „ingestion of breast milk or processed milk products with drinking water“ by the reference person „≤ 1a“ these two sub-pathways shall be considered alternatively. For the sub-pathway „ingestion of processed milk products with drinking water“ it shall be assumed that supraregionally produced and therefore not contaminated powdered milk is prepared using drinking water contaminated due to mining. The higher one of these two exposure levels shall be assumed when calculating mining-caused radiation exposure due to „ingestion of brest milk or processed milk products with drinking water“.

e) If the contamination pathway „release with water" involves consideration of both ground water and surface water contaminations, each of the sub-pathways shall be considered alternatively for ground water and surface water contamination. The sub-pathway associated with the higher one of the two exposure levels shall be assumed to calculate the mining-caused radiation exposure.

2.6.5 Inhalation of radon and its short-lived decay products

a) Generally, radiation exposure from mining is significantly influenced by inhalation of ^{222}Rn and its short-lived decay products. This case is referred to in Paras 2.6.5.1 to 2.6.5.4. below.

b) Additionally, the inhalation of short-lived decay products of the radon isotope ^{220}Rn at workplaces may make a contribution to radiation exposure from mining. The relevance according to Part I, Para 2.2 shall be verified on an individual basis. Realistic assumptions of periods of stay at workplaces shall be made. Part I, Para 2.3.1 b) or c) shall be observed.

2.6.5.1 As a general rule, all mining installations and sites shall be factored into the test of the exemption criterion under Part I, Para 2.3.2 a), and Part I, Para 2.6.5.4 shall be observed. The levels of mining-caused ^{222}Rn concentrations at exposure sites of reference persons may be assessed by measurements, via modelling, or estimated according to Annex VI. The following stipulations shall be observed:

a) The exemption criterion is absolutely applicable. Any differentiated application accounting for modifying factors such as periods of stay, or equilibrium factor at the site of exposure is unacceptable.

b) Measurements of ^{222}Rn concentration comprise not only mining-caused levels but also naturally occurring concentrations of ^{222}Rn. 10 Bq m^{-3} is a representative value for the latter according to Part I, Para 3.2 b). Correspondingly, the exemption criterion shall be deemed to be fulfilled with measured values of up to 15 Bq m^{-3}. Contributions to mining-caused radiation exposure of reference persons of the general public are only made when these latter are staying at exposure sites of which the representative measured level of ^{222}Rn concentration exceeds 15 Bq m^{-3}. For workers Part I, Para 2.3.1 b) shall be observed.

2.6.5.2 Part I, Para 2.6.7 shall be observed when using release and transport models.

2.6.5.3 a) The simplified procedure according to Annex VI serves a conservative definition of hypothetical exposure sites for which a mining-caused ^{222}Rn concentration exceeding 5 Bq m^{-3} on the annual average cannot be excluded. More precise information on the actual conditions at a given site may be obtained by measuring the ^{222}Rn concentration according to Part I, Para 2.6.5.1 b) or by computation according to Part I, Para 2.6.7.

b) The procedure may be used for individual mining residues (single sources) as well as for multiple sources characterized by exceedance of the exemption criterion of 5 Bq m^{-3} by the total of all mining installations and facilities of a given site. This procedure determines the mining-caused level of ^{222}Rn concentration at, and in the vicinity of mining installations and facilities.

c) The simplified procedure is based on a generalisation of site-specific model computations carried out for uranium ore mining dumps. It takes account not only of the dump type but also of the different meteorologic and topographic site conditions. The procedure is useful for mine dumps and other plane residues, but also for other types of ^{222}Rn emitters (e.g. shafts, galleries) [1)].

d) The simplified procedure to test the exemption criterion according to Annex VI rests upon known representative values of the mining-caused ^{222}Rn exhalation rate. These may be obtained by measurements or via release models, or estimated from representative measured values of the activity concentration of ^{226}Ra or of the gamma local dose rate using approximations which are also given in Annex VI. The proportion of naturally occurring environmental radioactivity shall be subtracted from the measured value used. Unless site-specific levels of natural environmental radioactivity are available, the general values of Table V.3 may be used.

2.6.5.4 The exemption criterion is deemed to be fulfilled for all mining installations and facilities complying with the following requirements (the requirements a) and b) are not applicable for type-3 mine dumps under Annex VI, Para 1.1):

a) area > 1 ha and mean ^{222}Rn emission rate < 2 kBq s^{-1} or

b) area < 1 ha and ^{222}Rn exhalation rate < 0.2 Bq m^{-2} s^{-1} or

c) distance from site of exposure > 4000 m with site type flat ground[2)] or

d) distance from site of exposure > 10000 m with site type mountainous ground[3)]

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[1] The simplified procedure is not applicable for dumps where dump fires may occur - e.g. as a result of high concentrations of pyrite. The associated increase in radon emanation due to convection is not covered by the models used.

[2] Ground with a slope of up to 1:20.

[3] Ground with a slope exceeding 1:20.

Accordingly, there is no need to account for these mining installations or facilities, neither when testing the exemption criterion nor when assessing mining-caused radiation exposure due to inhalation of ^{222}Rn and its short-lived decay products, if required. This applies as a general rule for all exposure sites at, and beyond (in the vicinity of) mining installations and facilities when the ^{222}Rn exhalation rate exhibits no large-scale inhomogeneities.

2.6.6 Direct soil ingestion

The exposure pathway "direct soil ingestion" shall not be considerd for age group „≤ 1 a".

2.6.7 Inputs for exposure calculation

Exposure calculation for all exposure pathways is based on known representative values of ambient dose equivalent rate, activity concentration in soil, food, air and water, as well as radon decay product concentration, potential alpha energy concentration, or ^{222}Rn concentration combined with the corresponding equilibrium factor, respectively. These values can be assessed by measurements or using mathematical models. The following principles and notes shall be observed:

a) Assessment of these representative values shall preferentially rest on measurements performed at the most unfavourable receiving points according to Part I, Para 2.3.2 b).

b) Calculations shall be performed especially in cases where

- measurement is technically impracticable or interpretation of measurement results is difficult,
- measurement would require undue efforts,
- future uses must be accounted for,
- changes in emission and immission parameters must be assumed, or
- assessment of radiation exposure must be related to an individual source in the presence of regional source accumulation.

2.6.8 Nuclides to be considered

As a general rule, the nuclides of the ^{238}U-series and of the ^{235}U-series have to be considered when calculating radiation exposure to mining-caused environmental radioactivity. In singular cases, where a mining-caused radiation exposure to nuclides for the ^{232}Th-series must be assumed or cannot be excluded, these nuclides shall be additionally included in the calculation. Part I, Para 2.2 shall be observerd.

3 Simplified procedure to assess radiation exposure from mining

Where radiation exposure calculation under Part Teil I, Para 2.6.7 a) is based on measured values, it has to be considered that each measured value also includes the contribution made by naturally occurring environmental radioactivity. This contribution must be subtracted from the measured value to obtain the level of mining-caused radiation exposure.

3.1 Two-stage procedure

The following two-stage procedure may be used to perform a screeening of compliance with dose limits or constraints (relevant dose levels) for mining-caused radiation exposure:

a) At the first stage, the level of radiation exposure calculated according to Part II, without deducting the contribution of natural exposure, is matched with the relevant dose levels. Unless these are exceeded for any reference person, compliance with the relevant dose levels may be assumed without any further evaluation. Otherwise, the procedure shall be continued as follows.

b) At the second stage, the general values of natural environmental radioactivity, as specified in the Tables of Annex V, are subtracted from the level of a reference person's radiation exposure assessed according to a). These values involve an average value of ambient dose equivalent rate and levels of acitivity concentration in food, soil and forage, as well as of activity concentration outdoors, in waters (drinking water, cattle watering trough water, spray irrigation water, surface water) and in dust, for a region not influenced by mining. Where site-specific values of natural environmental radioactivity according to Part I, Para 3.2 are available, these shall be used instead of the general values of natural environmental radioactivity. The remaining amount of radiation exposure determined that way shall be deemed to be the mining-caused radiation exposure of the reference person for the purpose of comparison with the relevant dose levels. If this comparison shows no exceedance for any reference person, compliance with the relevant dose levels may be assumed without any further check.

3.2 Site-specific values of natural environmental radioactivity

Site-specific values of naturally occurring environmental radioactivity are required to assess mining-caused radiation exposure where compliance with the relevant dose levels cannot be established using the simplified procedure according to Part I, Para 3.1 These values shall be determined in consultation with the competent authorities.

PART II CALCULATION PROCEDURES

1 Calculation of external exposure to gamma radiation from soil outdoors or indoors

Calculation of mining-caused effective annual dose $E_{A,j}$ shall be based on representative measurement values of ambient dose equivalent rate[1)] outdoors at conceivable exposure sites s of reference person j as follows:

$$E_{A,j} = f_{Con,j} \cdot \sum_{s} \left(\dot{H}^*(10)_s - \dot{H}^*(10)^U \right) \cdot t_{Exp,j,s} \cdot a_s \qquad (1.1)$$

$E_{A,j}$ Effective annual dose[2)] from gamma radiation for reference person j [Sv]

$\dot{H}^*(10)_s$ Ambient dose equivalent rate outdoors at a height of 1 m at exposure site s [Sv h^{-1}]

$\dot{H}^*(10)^U$ Ambient dose equivalent rate of natural gamma radiation outdoors at a height of 1 m [Sv h^{-1}]; see Part I, Para 3, or Annex V, Para V.1, respectively

(When the natural background is subtracted according to Part I, Para 3.2, allowance shall be made for dependence on exposure site)

$f_{Con,j}$ Conversion factor from ambient dose equivalent to effective dose for reference person j; see Annex I, Table I.1

$t_{Exp,j,s}$ Annual time spent by reference person j at exposure site s [h]; see Annex I, Table I.2

a_s Factor accounting for the shielding effect on gamma radiation outdoors at exposure site s, dimensionless; see Annex I, Table I.3

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[1] Up to July 31, 2011, the operational quantity “photon dose equivalent rate” might as well be indicated instead of the local dose rate.
[2] In the following „effective annual dose“ represents the mining-caused effective annual dose.

Note:

If the ambient dose equivalent rate outdoors at a height of 1 m has to be calculated from the level of activity concentration of the upper soil layer (see Part I, Para 2.6.7 b)), the corresponding quantities usually (see Part I, Para 2.6.8) are given by:

$$\dot{H}^*(10)_s = C_{Soil,s} \cdot g_{ext} \tag{1.2}$$

and

$$\dot{H}^*(10)^U = C_{Soil}^U \cdot g_{ext} \tag{1.3}$$

where

$C_{Soil,s}$	Activity concentration of a radionuclide of the ^{238}U-series in radioactive equilibrium at the upper soil layer (0 - 30 cm) for exposure site s [Bq kg^{-1} (DM)][1)]
C_{Soil}^U	Natural background activity concentration of a radionuclide of the ^{238}U-series in radioactive equilibrium at the upper soil layer (0 - 30 cm) [Bq kg^{-1} (DM)]; see Part I, Para 3 or Annex V, Table V.5, respectively
g_{ext}	Conversion factor to convert activity concentration of soil (^{238}U-series in radioactive equilibrium) into ambient dose equivalent rate outdoors at a height of 1 m [Sv kg Bq^{-1} h^{-1}] where $g_{ext} = 5.3 \cdot 10^{-10}$ Sv kg Bq^{-1} h^{-1}

In the absence of radioactive equilibrium, ^{226}Ra-activity shall be determined in the upper soil layer, since the main contribution to external gamma radiation results from decay of the two short-lived decay products ^{214}Pb and ^{214}Bi.

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[1] DM: Dry Mass.

2 Calculation of radiation exposure from inhalation of dust outdoors and indoors

Effective annual dose $E_{Inh,j}$ of reference person j from inhalation of dust is calculated as follows:

$$E_{Inh,j} = \dot{V}_j \cdot \sum_s \sum_r \left(C_{Air,r,s} - C^U_{Air,r}\right) \cdot g_{Inh,r,j} \cdot t_{Exp,j,s} \cdot a_{Air,s} \qquad (2.1)$$

where

$E_{Inh,j}$	Effective annual dose from inhalation of dust for reference person j [Sv]
$C_{Air,r,s}$	Activity concentration of the particle-bound radionuclide r in outdoor air, for exposure site s [Bq m^{-3}]
$C^U_{Air,r}$	Natural background activity concentration of the particle-bound radionuclide r in outdoor air [Bq m^{-3}], see Part I, Para 3 or Annex V, Table V.2, respectively (If $C_{Air,r,s}$ solely includes the mining-caused fraction by reason of model calculations or use of equation (2.1a), then $C^U_{Air,r} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2., account has to be taken of a dependence on exposure site s.)
$\dot{V}_j$	Breathing rate for reference person j [m^3 h^{-1}]; see Annex II, Table II.1
$g_{Inh,r,j}$	Inhalation dose coefficient for radionuclide r and reference person j [Sv Bq^{-1}]; see Annex II, Table II.2
$t_{Exp,j,s}$	Annual time spent at exposure site s by reference person j [h]; see Annex I, Table I.2
$a_{Air,s}$	Factor to determine the level of dust concentration at exposure site s from dust concentration outdoors, dimensionless ($a_{Air,s} = 1$ for time spent outdoors and $a_{Air,s} = 0.5$ for time spent indoors)

Notes:

a)

The following radionuclides shall be considered when assessing radiation exposure: ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{235}U, ^{231}Pa and ^{227}Ac (Part I, Para 2.6.8 shall be observed).

b)

In the absence of a site-specific value, the activity concentration for exposure site s, $C_{Air,r,s}$, resulting from resuspension at, or in the vicinity of, mining installations or facilities (up to a distance of 100 m; see Part I, Para 2.6.3 c)) may be estimated as follows based on the level of activity concentration of soil, using a reference value of airborne particles concentration:

$$C_{Air,r,s} = \left(C_{Soil(0.02),r,s} - C^{U}_{Soil(0.02),r}\right) \cdot S_{Dust} \qquad (2.1a)$$

Where:

$C_{Soil(0.02),r,s}$ Activity concentration of radionuclide r in the dust fraction (particle diameter < 0.02 mm) of the soil layer relevant for dust formation, for exposure site s [Bq kg^{-1} (DM)]

$C^{U}_{Soil(0.02),r}$ Natural background activity concentration of radionuclide r in the dust fraction (particle diameter < 0.02 mm) of the soil layer relevant for dust formation [Bq kg^{-1} (DM)], see Part I, Para 3 or Annex V, Table V.5, respectively

(If $C_{Soil(0.02),r,s}$ solely includes the mining-caused fraction by reason of model calculations or use of equation (2.1b), then $C^{U}_{Soil(0.02),r} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2, account has to be taken of a dependence on exposure site s.)

S_{Dust} Reference value of airborne particles concentration: $5 \cdot 10^{-8}$ kg m^{-3}

c)

In the absence of a site-specific value, the activity concentration $C_{Luft,r,s}$ resulting from occupational activity or work at mining installations or facilities may be estimated from activity concentration of soil using a technical reference value of airborne particles concentration $S_{Dust} = 5 \cdot 10^{-7}$ kg m^{-3} for exposure site s according to equation (2.1a).

d)

If activity concentration levels are available only for the whole (unsieved) soil sample, activity concentration $C_{Soil(0.02),r,s}$ can be calculated as follows, using a concentration factor derived from examinations of comparable soil materials (especially similar proportion of dust fraction):

$$C_{Soil(0.02),r,s} = \left(C_{Soil,r,s} - C^{U}_{Soil,r}\right) \cdot CF_{0.02,r} \qquad (2.1b)$$

Where:

$C_{Soil,r,s}$ Activity concentration of radionuclide r in the whole (unsieved) sample from the soil layer relevant for dust formation, for exposure site s [Bq kg^{-1} (DM)]

$C^{U}_{Soil,r}$ Natural background activity concentration of radionuclide r in the whole (unsieved) sample from the soil layer relevant for dust formation [Bq kg^{-1} (DM)], see Part I, Para 3 or Annex V, Table V.5, respectively

(If $C_{Soil,r,s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{Soil,r} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2, account has to be taken of a dependence on exposure site s)

$CF_{0.02,r}$ Concentration factor describing the mean ratio of activity concentration of radionuclide r in the dust fraction to that in the whole sample, dimensionless ($CF_{0.02,r} = 4$ for all radionuclides r)

e)

In the presence of both the natural isotope ratio of the ^{238}U-series to the ^{235}U-series and radioactive equilibrium within each decay chain, radiation exposure may be calculated from the activity concentration of a particle-bound radionuclide from the ^{238}U-series using the inhalation dose coefficient for the radionuclide mixture as follows:

$$E_{Inh,j} = \dot{V}_j \cdot g_{Inh,j} \cdot \sum_s \left(C_{Air,s} - C^{U}_{Air}\right) \cdot t_{Exp,j,s} \cdot a_{Air,s} \qquad (2.1c)$$

Except for those already defined, the above symbols represent:

$C_{Air,s}$ Activity concentration of a particle-bound radionuclide from the ^{238}U-series in outdoor air for exposure site s [Bq m^{-3}]

C^{U}_{Air} Natural background activity concentration of a particle-bound radionuclide from the ^{238}U-series in outdoor air [Bq m^{-3}], see Part I, Para 3

(If $C_{Air,s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{Air,r} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2., account has to be taken of a dependence on exposure site s)

$g_{Inh,j}$ Inhalation dose coefficient for reference person j and the radionuclide mixture [Sv Bq^{-1}], see Annex II, Table II. 2

f)

If the activity concentration of the particle-bound long-lived alpha activity, i.e. the sum of the activity concentrations of the five nuclides ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra and ^{210}Po, is utilized as a measurand, radiation exposure may be calculated as follows using the inhalation dose coefficient for the radionuclide mixture, provided that the radionuclides of the ^{238}U-chain are in radioactive equilibrium:

$$E_{Inh,j} = \frac{1}{5} \cdot \dot{V}_j \cdot g_{Inh,j} \cdot \sum_s \left(C_{Air,LLA,s} - C^{U}_{Air,LLA}\right) \cdot t_{Exp,j,s} \cdot a_{Air,s} \qquad (2.1d)$$

Except for those already defined, the above symbols represent:

$C_{Air,LLA,s}$ Activity concentration of particle-bound long-lived alpha emitters of the ^{238}U-series in the outdoor air for exposure site s [Bq m^{-3}]

$C^{U}_{Air,LLA}$ Natural background activity concentration of particle-bound long-lived alpha emitters from the ^{238}U-series in the outdoor air [Bq m^{-3}], see Part I, Para 3

(If $C_{Air,LLA,s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{Air,LLA} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2, account has to be taken of a dependence on exposure site s)

If the ^{238}U-series and the ^{235}U-series are not in radioactive equilibrium and the relative activity ratio given by each of the nuclides specified in Part II, Para 2 a) related to both these decay chains is known, then radiation exposure can be calculated as follows using long-lived alpha-activity, provided that there is natural activity ratio between ^{238}U and ^{235}U and that the activity concentration of the nuclide $^{238}U > 0$[1]:

$$E_{Inh,j} = \dot{V}_j \cdot \sum_s \left(C_{Air,LLA,s} - C^U_{Air,LLA}\right) \cdot t_{Exp,j,s} \cdot a_{Air,s}$$

$$\times \frac{1}{\left(1 - p_{Pb-210,s}\right)} \cdot \left(\sum_{r=1}^{6} p_{r,s} \cdot g_{Inh,r,j} + 0.05 \cdot \frac{p_{U-238,s}}{p_{U-235,s}} \cdot \sum_{r=7}^{9} p_{r,s} \cdot g_{Inh,r,j} \right) \qquad (2.1e)$$

Except for those already defined, the above symbols represent:

$p_{r,s}$	Fraction of a nuclide r from the ^{238}U-series, or from the ^{235}U-series as specified in Part II, Para 2 a) relative to total activity concentration of the decay chain at exposure site s, where $\sum_{r=1}^{6} p_r = 1$ or $\sum_{r=7}^{9} p_r = 1$, respectively, dimensionless
$p_{Pb-210,s}$	Fraction of nuclide ^{210}Pb relative to total activity concentration of the ^{238}U-series at exposure site s
$p_{U-238,s}$	Fraction of nuclide ^{238}U relative to total activity concentration of the ^{238}U-series at exposure site s
$p_{U-235,s}$	Fraction of nuclide ^{235}U relative to total activity concentration of the ^{235}U-series at exposure site s
r	Nuclide index r = 1, 2, 3, 4, 5 and 6 stands for the nuclides of the ^{238}U-series specified in Part II, Para 2 a), and r = 7, 8 and 9 stands for the nuclides of the ^{235}U-series specified in Part II, Para 2 a)

[1] From these premises it follows that $p_{U-238} \neq 0$, $p_{U-235} \neq 0$ und $p_{Pb-210} \neq 1$.

3 Calculation of radiation exposure from inhalation of radon und its short-lived decay products

3.1 Calculation of radiation exposure from inhalation of ^{222}Rn and its short-lived decay products

Calculation of radiation exposure from inhalation of ^{222}Rn and its short-lived decay products is based on the dose conversion convention recommended in ICRP Publication 65 as referred to by the Directive 96/29/Euratom of 13 May 1996 whereby assessment of effective dose from potential alpha energy exposure[1)] is permissible. Potential alpha energy exposure may be determined either from values of ^{222}Rn concentration (if the equilibrium factor and period of stay are known) or from potential alpha energy concentration (if the period of stay is known).

3.1.1 Calculating radiation exposure based on ^{222}Rn concentration values

Effective annual dose $E_{Rn-222,j}$ of reference person j is calculated from levels of ^{222}Rn concentration $C_{Rn,s}$ as follows:

$$E_{Rn-222,j} = g_{EEC(Rn-222),j} \cdot \sum_s \left(C_{Rn-222,s} - C^{U}_{Rn-222}\right) \cdot F_{Rn-222,s} \cdot t_{Exp,j,s} \qquad (3.1)$$

where:

$E_{Rn-222,j}$ Effective annual dose from inhalation of ^{222}Rn and its short-lived decay products for reference person j [Sv]

$C_{Rn-222,s}$ Mean annual ^{222}Rn concentration in outdoor air for exposure site s [Bq m^{-3}]

C^{U}_{Rn-222} ^{222}Rn concentration of the natural background in outdoor air [Bq m^{-3}], see Part I, Para 3

(If $C_{Rn-222,s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{Rn-222} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2., account has to be taken of a dependence on exposure site s)

$F_{Rn-222,s}$ Factor describing radioactive equilibrium between the mining-caused ^{222}Rn and its short-lived progeny at exposure site s (equilibrium factor, dimensionless, see Annex III, Table III.2)

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[1] Potential alpha energy exposure stands for the time integral of potential alpha energy concentration of the short-lived ^{222}Rn decay products over the exposure time.

$g_{EEC(Rn-222),j}$ Dose conversion coefficient of reference person j for the product of ^{222}Rn exposure and equilibrium factor [Sv m^3 Bq^{-1} h^{-1}], see Annex III, Table III.1

$t_{Exp,j,s}$ Annual time spent by reference person j at exposure site s [h], see Annex I, Table I.2

3.1.2 Calculating radiation exposure based on values of potential alpha energy concentration of short-lived ^{222}Rn decay products

Effective annual dose $E_{Rn-222,j}$ of reference person j is calculated from values of potential alpha energy concentration $C_{pot(Rn-222),s}$ as follows:

$$E_{Rn-222,j} = g_{pot(Rn-222),j} \cdot \sum_s \left(C_{pot(Rn-222),s} - C^U_{pot(Rn-222)}\right) \cdot t_{Exp,j,s} \qquad (3.2)$$

Except for those already defined, the above symbols represent:

$C_{pot(Rn-222),s}$ Mean annual potential alpha energy concentration of the short-lived ^{222}Rn decay products in outdoor air for exposure site s [J m^{-3}]

$C^U_{pot(Rn-222)}$ Potential alpha energy concentration of short-lived ^{222}Rn decay products of natural background in outdoor air [J m^{-3}], see Part I, Para 3

(If $C_{pot(Rn-222),s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^U_{pot(Rn-222)} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2., account has to be taken of a dependence on exposure site s)

$g_{pot(Rn-222),j}$ Dose conversion coefficient of reference person j for potential alpha energy exposure to short-lived ^{222}Rn decay products, [Sv m^3 J^{-1} h^{-1}], see Annex III, Table III.1

3.2 Calculation of radiation exposure from inhalation of ^{220}Rn and its short-lived decay products

Calculation of radiation exposure from inhalation of ^{220}Rn and its short-lived decay products is based on a dose coefficient resting upon the dosimetric lung model recommended in ICRP Publication 50. The present Calculation Guide only refers to inhalation of short-lived decay products since the radiation risk from inhalation of ^{220}Rn is negligible. The quoted dose coefficient therefore only relates to short-lived decay products. It only applies for calculating effective doses at the workplace ("workers" and “reference person >17a" according to Part I, Para 2.3.1 b)).

Effective annual dose $E_{Rn-220,j}$ of reference person j is calculated from values of potential alpha energy concentration $C_{pot(Rn-220),s}$ as follows:

$$E_{Rn-220,j} = g_{pot(Rn-220),j} \cdot \sum_{s} \left(C_{pot(Rn-220),s} - C^{U}_{pot(Rn-220)} \right) \cdot t_{Exp,j,s} \qquad (3.3)$$

Except for those already defined, the above symbols represent:

$E_{Rn-220,j}$ Effective annual dose from inhalation of ^{220}Rn and its short-lived decay products for reference person j [Sv]

$C_{pot(Rn-220),s}$ Potential alpha energy concentration of short-lived ^{220}Rn progeny in respiratory air for exposure site s [J m^{-3}]

$C^{U}_{pot(Rn-220)}$ Potential alpha energy concentration of the short-lived ^{220}Rn progeny of natural background in respiratory air [J m^{-3}], see Part I, Para 2.6.5 b)

(If $C_{pot(Rn-220),s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{pot(Rn-220),j} \equiv 0$.)

$g_{pot(Rn-220),j}$ Dose coefficient of reference person j for potential alpha energy exposure to short-lived ^{220}Rn progeny [Sv m^{3} J^{-1} h^{-1}] (at workplaces: $g_{pot(Rn-220),j} = 0.5$ Sv m^{3} J^{-1} h^{-1})

4 Calculation of radiation exposure from ingestion of locally produced food

According to Part II, Para 2.6.7 the calculation of radiation exposure from locally produced food shall be based on representative measurement values of both activity concentration in vegetal and animal products intended for human consumption and activity concentration in drinking water. However, use of the calculation instructions of Part II, Para 6, which base upon values of activity concentration in the soil and activity concentration in surface waters, spray irrigation und cattle watering tanks, should be limited to the cases covered by Part I, Para 2.6.7 b).

Effective annual dose $E_{Ing,j}$ of reference person j from ingestion of locally produced food is calculated as follows:

$$E_{Ing,j} = \sum_n p_n \cdot U_{n,j} \cdot \sum_r \left(C_{n,r} - C^U_{n,r}\right) \cdot g_{Ing,r,j} \qquad (4.1)$$

where:

$E_{Ing,j}$ Effective annual dose for reference person j from ingestion of locally produced food [Sv]

$C_{n,r}$ Activity concentration of radionuclide r in food n [Bq kg^{-1}] ([Bq L^{-1}] for n = W)

$C^U_{n,r}$ Natural background activity concentration of radionuclide r in food n [Bq kg^{-1}] ([Bq L^{-1}] for n = W), see Part I, Para 3 or Annex V, Table V.4, respectively

(If $C_{n,r}$ solely includes the mining-caused fraction by reason of model calculations, then $C^U_{n,r} \equiv 0$.)

n Index label for foodstuffs

n = Mi	milk and milk products
n = Me	meat und meat products
n = Fi	fish
n = Ve	vegetables except for leafy and root vegetables
n = LV	leafy vegetables
n = RV	root vegetables
n = Fr	fruit

	n = W	drinking water
	n = BM	breast milk
	n = PM	processed milk products
p_n	Fraction of local production of foodstuff n in the annual consumption, dimensionless, see Annex IV, Table IV.4	
$U_{n,j}$	Annual consumption of foodstuff n by reference person j [kg] ([L] for n = W), see Annex IV, Table IV.2	
$g_{Ing,r,j}$	Ingestion dose coefficient for radionuclide r and reference person j [Sv Bq^{-1}], see Annex IV, Table IV.1	

Notes:

a)

The following radionuclides have to be accounted for when determining radiation exposure from ingestion: ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{235}U, ^{231}Pa and ^{227}Ac (Part I, Para 2.6.8 shall be observed). If activity concentration is assessed by measurement, it has to be considered that the radioactive equilibrium within the ^{238}U-series and the ^{235}U-series might be assumed to be disturbed in the quoted foodstuffs.

b)

Radiation exposure from consumption of milk and milk products as well as meat und meat products shall only be considered for those areas contaminated by mining installations or facilities that are suitable for pasture farming and have 1 ha size at minimum. The sub-pathways spray irrigation of range plants and cattle watering trough shall be accounted for if the quality and amount of waters available are suitable and sufficient for this use, see also Part I, Para 2.6.4 c). Assuming a spray irrigation rate of 1 L m^{-2} d^{-1} (Annex IV, Table IV.4) and an average spray irrigation time of 1 h d^{-1}, a minimum capacity of 10 m^3 h^{-1} is obtained for spray irrigation of the above area. This value is reduced accordingly if water retention devices can be used. The daily water consumption by cattle is 75 L (Annex IV, Table IV.4).

c)

When the caluclation of radiation exposure from ingestion of vegetal and animal products is based on representative measurement values in these foodstuffs, assuming that

- the area under cultivation is situated on mining installations or facilities,
- only the terrestrial exposure pathways are relevant (no spray irrigation and no cattle watering trough) and
- that a representative value of activity concentration for the upper soil layer is available,

then the fraction of natural background activity shall be accounted for as follows:

$$E_{Ing,n,j} = \sum_{n} p_n \cdot U_{n,j} \cdot \sum_{r} C_{n,r} \cdot \left(1 - C^U_{Soil,r} / C_{Soil,r}\right) \cdot g_{Ing,r,j} \qquad (4.1a)$$

Except for those already defined, the above symbols represent:

$E_{Ing,n,j}$	Effective annual dose for reference person j from ingestion of locally produced foodstuff n [Sv]
$C^U_{Soil,r}$	Natural background activity concentration of radionuclide r in the upper soil layer (0 - 10 cm for soil from pasture, 0 - 30 cm for soil from garden and arable land) [Bq kg^{-1} (DM)], see Part I, Para 3 or Annex V, Table V.5, respectively
$C_{Soil,r}$	Representative value of activity concentration of radionuclide r for the upper soil layer (0 - 10 cm for soil from pasture, 0 - 30 cm for soil from garden and arable land) [Bq kg^{-1} (DM)]

d)

No natural background activity concentration shall be accounted for when determining radiation exposure based on measurement values of activity concentration in breast milk.

5 Calculation of radiation exposure from soil ingestion (direct ingestion)

Effective annual dose $E_{Ing,Soil,j}$ of reference person j from direct soil ingestion shall be calculated as follows:

$$E_{Ing,Soil,j} = U_{Soil,j} \cdot \sum_s t_{Exp,j,s} \cdot \sum_r \left(C_{Soil(0.5),r,s} - C^U_{Soil(0.5),r} \right) \cdot g_{Ing,r,j} \qquad (5.1)$$

where:

$E_{Ing,Soil,j}$ Effective annual dose for reference person j from direct soil ingestion [Sv]

$C_{Soil(0.5),r,s}$ Activity concentration of radionuclide r in the fine grain fraction (particle diameter < 0.5 mm) of the upper soil layer (0 - 30 cm) at exposure site s [Bq kg^{-1} (DM)]

$C^U_{Soil(0.5),r}$ Natural background activity concentration of radionuclide r in der fine grain fraction of the upper soil layer (0 - 30 cm) [Bq kg^{-1} (DM)], see Part I, Para 3 or Annex V, Table V.5

(If $C_{Soil(0.5),r,s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^U_{Soil(0.5),r} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2., account has to be taken of a dependence on exposure site s)

$U_{Soil,j}$ Soil uptake rate of reference person j [kg h^{-1}], see Annex IV, Table IV.5

$t_{Exp,j,s}$ Annual time spent by reference person j at exposure site s [h], see Annex I, Table I.2

$g_{Ing,r,j}$ Ingestion dose coefficient for radionuclide r and reference person j [Sv Bq^{-1}], see Annex IV, Table IV.1

Notes:

a)

The following radionuclides have to be accounted for when determining radiation exposure from ingestion: ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{235}U, ^{231}Pa and ^{227}Ac (Part I, Para 2.6.8 shall be observed).

b)

If values of activity concentration are only available for the whole (unsieved) soil sample, then the activity concentration $C_{Soil(0.5),r,s}$ can be calculated as follows using a concentration factor derived from examinations of comparable soil materials (especially with a similar fine grain fraction):

$$C_{Soil(0.5),r,s} = \left(C_{Soil,r,s} - C^{U}_{Soil,r}\right) \cdot CF_{0.5,r} \qquad (5.1a)$$

where:

$C_{Soil,r,s}$ — Activity concentration of radionuclide r in the whole (unsieved) sample of the upper soil layer (0 - 30 cm) [Bq kg^{-1} (DM)]

$C^{U}_{Soil,r}$ — Natural background activity concentration of radionuclide r in the whole (unsieved) sample of the upper soil layer (0 - 30 cm) [Bq kg^{-1} (DM)], see Part I, Para 3 or Annex V, Table V.5, respectively

(If $C_{Soil,r,s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{Soil,r} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2., account has to be taken of a dependence on exposure site s)

$CF_{0.5,r}$ — Concentration factor describing the mean ratio of activity concentrations of radionuclide r of the fine grain fraction to the whole sample, dimensionless ($CF_{0.5,r}$ = 2 holds for all radionuclides r)

c)

Assuming both the natural isotopic ratio between the ^{238}U-series and the ^{235}U-series and radioactive equilibrium in these decay chains, radiation exposure may be calculated based on the activity concentration of one of the radionuclides of the ^{238}U-series quoted above under a) using the ingestion dose coefficient for the radionuclide mixture, according to the following equation:

$$E_{Ing,j} = U_{Soil,j} \cdot g_{Ing,j} \cdot \sum_{s} \left(C_{Soil(0.5),s} - C^{U}_{Soil(0.5)}\right) \cdot t_{Exp,j,s} \qquad (5.1b)$$

Except for those already defined, the above symbols represent:

$C_{Soil(0.5),s}$ Activity concentration in the fine grain fraction (particle diameter < 0.5 mm) of the upper soil layer (0 - 30 cm) at exposure site s for a radionuclide of the ^{238}U-series in radioactive equilibrium [Bq kg^{-1} (DM)]

$C^{U}_{Soil(0.5)}$ Natural background activity concentration in the fine grain fraction of the upper soil layer (0 - 30 cm) for a radionuclide of the ^{238}U-series in radioactive equilibrium [Bq kg^{-1} (DM)], see Part I, Para 3 or Annex V, Table V.5, respectively

(If $C_{Soil,s}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{Soil} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2., account has to be taken of a dependence on exposure site s).

$g_{Ing,j}$ Ingestion dose cefficient for the radionuclide mixture and reference person j [Sv Bq^{-1}], see Annex IV, Table IV.1

d)

For the purpose of determining radiation exposure, the radionuclide ^{210}Po shall be assumed to be available in inorganic form, and the dose coefficients quoted in brackets in Annex IV, Table IV.1 shall be used for this reason.

6 Calculation of activity concentration in food

6.1 Fish

The activity concentration $C_{Fi,r}$ of radionuclide r in fish is given by:

$$C_{Fi,r} = \left(C_{SurfW,r} - C^{U}_{SurfW,r}\right) \cdot T_{Fi,r} \qquad (6.1)$$

where:

$C_{SurfW,r}$ Activity concentration of radionuclide r in surface water [Bq L^{-1}]

$C^{U}_{SurfW,r}$ Natural background activity concentration of radionuclide r in surface water [Bq L^{-1}], see Part I, Para 3 or Annex V, Table V.6, respectively

(If $C_{SurfW,r}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{SurfW,r} \equiv 0$).

$T_{Fi,r}$ Concentration factor for radionuclide r in fish [L kg^{-1}], see Annex IV, Table IV.3

6.2 Plants

When determining activity concentration $C_{n,r}$ of radionuclide r in plant n (n = LV, leafy vegetables), (n = Pl, plants without leafy vegetables) und (n = PP, pasture plants) the following cases are considered:

- plants growing on mining installations or facilities:
  - root transfer from the upper soil layer and activity depositions (dust, soil particles) on surface plant components (pathway D, see Part II, Para 6.2.1)
  - spray irrigation (pathway B, see Part II, Para 6.2.2)

$$C_{n,r} = C_{D,n,r} + C_{B,n,r} \qquad (6.2a)$$

- plants growing in the vicinity of mining installations or facilities:
  - dust deposition on surface plant components (pathway A, see Part II, Para 6.2.3)
  - spray irrigation (pathway B)

$$C_{n,r} = C_{B,n,r} + C_{A,n,r} \qquad (6.2b)$$

where:

$C_{D,n,r}$ Activity concentration of radionuclide r in plant n via pathway D [Bq kg^{-1} (FM)][1)], see equation (6.3)

$C_{B,n,r}$ Activity concentration of radionuclide r in plant n via pathway B [Bq kg^{-1} (FM)], see equation (6.4)

$C_{A,n,r}$ Activity concentration of radionuclide r in plant n via pathway A [Bq kg^{-1} (FM)], see equation (6.5)

6.2.1 Plants via soil pathway - pathway D

Activity concentration $C_{D,n,r}$ in the plants growing on mining installations or facilities shall be calculated as follows from the representative values of activity concentration $C_{Soil,r}$ for the upper soil layer (0 – 10 cm for pasture soil, 0 - 30 cm for soil from arable land and garden soil):

$$C_{D,n,r} = T_{n,r} \cdot \left(C_{Soil,r} - C^{U}_{Soil,r}\right) \qquad (6.3)$$

Except for those already defined, the above symbols represent:

$T_{n,r}$ Transfer factor from soil to plant n (via root uptake and activity deposition on surface plant components) for radionuclide r [Bq kg^{-1} (FM) of plant per Bq kg^{-1} (DM) of soil], see Annex IV, Table IV.3

n Index label for plants

n = PP for pasture plants

n = Pl for plants without leafy vegetables

n = LV for leafy vegetables

6.2.2 Plants via the water pathway (spray irrigation) - pathway B

Activity concentration $C_{B,n,r}$ in plant n from spray irrigation of pastures, fields and gardens using water of activity concentration $C_{Irr,r}$ is calculated as follows:

---

[1] FM: Fresh Mass.

$$C_{B,n,r} = \left(C_{Irr,r} - C^{U}_{Irr,r}\right) \cdot \frac{W \cdot f_w}{Y_n \cdot \lambda_{eff,Pl,r}} \cdot \left(1 - e^{-\lambda_{eff,Pl,r}\, t_{n,w}}\right) \qquad (6.4)$$

where:

$C_{Irr,r}$ Activity concentration of radionuclide r in spray irrigation water [Bq L^{-1}]

$C^{U}_{Irr,r}$ Natural background activity concentration of radionuclide r in spray irrigation water [Bq L^{-1}], see Part I, Para 3 or Annex V, Table V.6, respectively

(If $C_{Irr,r}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{Irr,r} \equiv 0$.)

W spray irrigation rate [L m^{-2} s^{-1}], see Annex IV, Table IV.4

f_w Fraction of activity deposited on the plant in the case of spray irrigation, see Annex IV, Table IV.4

Y_n Yield or vegetation density [kg (FM) m^{-2}], see Annex IV, Table V.4

$\lambda_{eff,Pl,r}$ Effective rate constant for the retention of radionuclide r on the plant [s^{-1}], see Annex IV, Table IV.4

$t_{n,w}$ Time of surface contamination due to spray irrigation of plants during the growth period [s], see Annex IV, Table IV.4

6.2.3 Plants via the air pathway - pathway A

The activity concentration $C_{A,n,r}$ in the plants growing in the vicinity of mining installations or facilities, determined from soil contamination rate $\dot{B}_r$ resulting from the deposition of the particle-bound radionuclide r is given by:

$$C_{A,n,r} = \left(\dot{B}_r - \dot{B}^{U}_r\right) \cdot \frac{1 - e^{-\lambda_{eff,Pl,r}\, t_{n,e}}}{Y_n \cdot \lambda_{eff,Pl,r}} \qquad (6.5)$$

where:

$\dot{B}_r$ Soil contamination rate resulting from the dry deposition of the particle-bound radionuclide r [Bq m^{-2} s^{-1}]

$\dot{B}_r^U$ Natural background soil contamination rate of radionuclide r [Bq m^{-2} s^{-1}], see Part I, Para 3 or Annex V, Table V.8, respectively

(If $\dot{B}_r$ solely includes the mining-caused fraction by reason of model calculations, then $\dot{B}_r^U \equiv 0$).

Y_n Yield or vegetation density [kg (FM) m^{-2}], see Annex IV, Table IV.4

$\lambda_{eff,Pl,r}$ Effective rate constant for the retention of radionuclide r on the plant [s^{-1}], see Annex IV, Table IV.4

$t_{n,e}$ Contamination time for plants from group n during the growth period [s], see Annex IV, Table IV.4

Note:

a)

If no site-specific value is available, a reference value of deposition velocity v_g may be used to estimate the soil contamination rate from activity concentration $C_{Air,r}$ of radionuclide r in the grond-level outdoor air (see Part II, Para 2) as follows:

$$\dot{B}_r = v_g \cdot \left(C_{Air,r} - C_{Air,r}^U\right) \quad (6.5a)$$

Except for those already defined, the above symbols represent:

v_g Deposition velocity [m s^{-1}]

where $v_g = 1 \cdot 10^{-2}$ m s^{-1}

b)

When calculating activity concentration $C_{A,n,r}$ in plants from dust deposition or spray irrigation according to equation (6.5) or (6.4), respectively, it is not necessary to take account of the foodstuff group „root vegetables".

6.3 Milk und milk products, meat und meat products

The following sub-pathways are considered to determine activity concentration $C_{n,r}$ of radionuclide r in the foodstuff milk (n = Mi) und meat (n = Me):

- Consumption of forage plants including the associated direct soil ingestion, as well as

- Cattle watering trough.

Here:

$$C_{n,r} = \left\{\left(C_{PP,r} - C^{U}_{PP,r}\right)\cdot M_{Fo} + \left(C_{Soil,r} - C^{U}_{Soil,r}\right)\cdot M_{Soil}\cdot f_p + \left(C_{CW,r} - C^{U}_{CW}\right)\cdot L\right\}\cdot T_{n,r} \qquad (6.6)$$

Except for those already defined, the above symbols represent:

$C_{PP,r}$ Activity concentration of radionuclide r in pasture plants [Bq kg^{-1} (FM)]. The calculation is given by equation (6.2a) or (6.2b)

$C^{U}_{PP,r}$ Natural background activity concentration of radionuclide r in pasture plants [Bq kg^{-1} (FM)], see Part I, Para 3 or Annex V, Table V.7, respectively

(If $C_{PP,r}$ solely includes the mining-caused fraction by reason of model calculations, or using equation (6.2a) or (6.2b), then $C^{U}_{PP,r} \equiv 0$.)

$C_{CW,r}$ Activity concentration of radionuclide r in water used for cattle watering trough [Bq L^{-1}]

$C^{U}_{CW,r}$ Natural activity concentration of radionuclide r in water used for cattle watering trough [Bq L^{-1}], see Part I, Para 3 or Annex V, Table V.6, respectively

(If $C_{CW,r}$ solely includes the mining-caused fraction by reason of model calculations, then $C^{U}_{CW,r} \equiv 0$.)

M_{Fo} Daily uptake of cattle pasture forage [kg (FM) d^{-1}] , see Annex IV, Table IV.4

M_{Soil} Daily uptake of soil by cattle during grazing on the pasture [kg (DM) d^{-1}], see Annex IV, Table IV.4

f_p Fraction of the year during which animals graze on the pasture, see Annex IV, Table IV.4

L Daily water consumption by cattle [L d^{-1}], see Annex IV, Table IV.4

$T_{n,r}$ Transfer factor from forage, cattle trough water and ingested soil to milk (n = Mi) or meat (n = Me) for radionuclide r [d kg^{-1}], see Annex IV, TableIV.3

6.4 Breast milk

The following sub-pathways are considered to determine activity concentration $C_{BM,r}$ of radionuclide r in breast milk:

- Food ingestion, and
- Dust inhalation.

Here:

$$C_{BM,r} = \frac{T_{BM,r}}{360} \cdot \sum_n p_n \cdot \left(C_{n,r} - C_{n,r}^U\right) \cdot U_{n,>17a} + \frac{T_{BM,Inh,r}}{360} \cdot \dot{V}_{>17a} \cdot \sum_s \left(C_{Air,s,r} - C_{Air,r}^U\right) \cdot a_{Air,s} \cdot t_{Exp,>17a,s} \quad (6.7)$$

where:

$C_{BM,r}$	Activity concentration of radionuclide r in breast milk [Bq L^{-1}]
p_n	Fraction of annually consumed foodstuff locally produced, dimensionless, see Annex IV, Table IV.4
$C_{n,r}$	Activity concentration of radionuclide r in food n [Bq kg^{-1}] ([Bq L^{-1}] for n = W)
$C_{n,r}^U$	Natural background activity concentration of radionuclide r in food n [Bq kg^{-1}] ([Bq L^{-1}] for n = W), see Part I, Para 3 or Annex V, Table V.4, respectively (If $C_{n,r}$ solely includes the mining-caused fraction by reason of model calculations, or using the equations given in Part II, Paras 6.1 to 6.3, then $C_{RP,r}^U \equiv 0$).
$T_{BM,r}$	Foodstuff to breast milk transfer factor for radionuclide r [d kg^{-1}], see Annex IV, Table IV.3
$U_{n,>17a}$	Annual consumption of foodstuff n by the reference person "> 17 a" [kg], see Annex IV, Table IV.2
$C_{Air,s,r}$	Activity concentration of the particle-bound radionuclide r in outdoor air for exposure site s [Bq m^{-3}]
$C_{Air,r}^U$	Natural background activity concentration of the particle-bound radionuclide r in outdoor air [Bq m^{-3}], see Part I, Para 3 or Annex V, Table V.2, respectively

(If $C_{Air,r,s}$ solely includes the mining-caused fraction by reason of model calculations, or using equation (2.1a), then $C^{U}_{Air,r} \equiv 0$. When the natural background is subtracted according to Part I, Para 3.2., account has to be taken of a dependence on exposure site s.)

$\dot{V}_{>17a}$ Breathing rate for the reference person "> 17a" [m^3 h^{-1}], see Annex II, Table II.1

$a_{Air,s}$ Factor to determine the dust concentration at exposure site s from the dust concentration outdoors, dimensionless ($a_{Air,s} = 1$ for time spent outdoors and $a_{Air,s} = 0.5$ for time spent indoors)

$T_{BM,Inh,r}$ Inhaled-dust-to-breast milk transfer factor for radionuclide r [d kg^{-1}], see Annex IV, Table IV.3

ANNEX I PARAMETERS TO CALCULATE EXTERNAL RADIATION EXPOSURE OUTDOORS AND INDOORS

Table I.1

Conversion factor $f_{Con,j}$ to obtain effective dose for reference person j from ambient dose equivalent

Reference person	$f_{Con,j}$
≤ 1 a	0.8
1 - 2 a	0.7
2 - 7 a	0.7
7 - 12 a	0.7
12 –17 a	0.6
> 17 a	0.6
worker	0.6

Table I.2

Annual exposure time $t_{Exp,j,s}$ for several exposure sites s and reference persons j

Exposure site	Reference person	Exposure time $t_{Exp,j,s}$ [h]
1. indoors:	Worker[1)]	up to 2000
	Member of the public[2)]	7000
2. outdoors:	Worker[2)]	up to 2000
	Member of the public[2)]	up to 2000
where the following values result for a member of the public, depending on local conditions, from:		
2.1 uncultivated mine dumps or uncultivated areas, contaminated by mining residues	≤ 1 a	0
	1 - 2 a	100
	2 - 7 a	250
	7 - 12 a	250
	12 -17 a	250
	> 17 a	100
2.2 garden areas[3)]	Member of the public[2)]	1000
2.3 traffic areas	Member of the public[2)]	1000
2.4 parks and recreation centres, children's play areas	Member of the public[2)]	1000

[1] The sum of exposure times from activites or work outdoors and indoors shall not exceed a total of 2000 h.
[2] All age groups.
[3] Areas serving noncommercial horticultural use.

Table I.3

Factor $a_{x,s}$ to allow for the shielding effect on gamma radiation at exposure site s

Expositionsort	$a_{x,s}$
1. outdoors	1
2. indoors	
2.1 solid construction buildings (brick, concrete, natural stone, timber frame construction and the like)	0.1
2.2 lightweight construction buildings (wooden prefabricate house and the like)	0.3

ANNEX II PARAMETERS TO CALCULATE INTERNAL RADIATION EXPOSURE FROM INHALATION OF DUST OUTDOORS AND INDOORS

Table II.1

Breathing rate $\dot{V}_j$ of reference person j

Reference person	Breathing rate $\dot{V}_j$ [$m^3 h^{-1}$]
≤ 1 a	0.12
1 - 2 a	0.22
2 - 7 a	0.36
7 - 12 a	0.64
12 -17 a	0.84
> 17 a	0.93
worker	1.2

Table II.2

Inhalation dose coefficient $g_{Inh,r,j}$ for radionuclide r and inhalation dose coefficient $g_{Inh,j}$ of the radionuclide mixture for reference person j

Radionuclide	$g_{Inh,r,j}$ and $g_{Inh,j}$ [Sv Bq^{-1}]			
	≤ 1 a	1 - 2 a	2 - 7 a	7 - 12 a
^{238}U-series:				
^{238}U	$1.2 \cdot 10^{-5}$	$9.4 \cdot 10^{-6}$	$5.9 \cdot 10^{-6}$	$4.0 \cdot 10^{-6}$
^{234}U	$1.5 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$	$7.0 \cdot 10^{-6}$	$4.8 \cdot 10^{-6}$
^{230}Th	$4.0 \cdot 10^{-5}$	$3.5 \cdot 10^{-5}$	$2.4 \cdot 10^{-5}$	$1.6 \cdot 10^{-5}$
^{226}Ra	$1.5 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$	$7.0 \cdot 10^{-6}$	$4.9 \cdot 10^{-6}$
^{210}Pb	$5.0 \cdot 10^{-6}$	$3.7 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$
^{210}Po	$1.5 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$	$6.7 \cdot 10^{-6}$	$4.6 \cdot 10^{-6}$
^{235}U-series:				
^{235}U	$1.3 \cdot 10^{-5}$	$1.0 \cdot 10^{-5}$	$6.3 \cdot 10^{-6}$	$4.3 \cdot 10^{-6}$
^{231}Pa	$2.2 \cdot 10^{-4}$	$2.3 \cdot 10^{-4}$	$1.9 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$
^{227}Ac	$1.7 \cdot 10^{-3}$	$1.6 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	$7.2 \cdot 10^{-4}$
^{232}Th-series:				
^{232}Th	$5.4 \cdot 10^{-5}$	$5.0 \cdot 10^{-5}$	$3.7 \cdot 10^{-5}$	$2.6 \cdot 10^{-5}$
^{228}Ra	$1.5 \cdot 10^{-5}$	$1.0 \cdot 10^{-5}$	$6.3 \cdot 10^{-6}$	$4.6 \cdot 10^{-6}$
^{228}Th	$1.6 \cdot 10^{-4}$	$1.3 \cdot 10^{-4}$	$8.2 \cdot 10^{-5}$	$5.5 \cdot 10^{-5}$
Mixture	$1.9 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$	$8.0 \cdot 10^{-5}$

Table II.2 (continued)

Inhalation dose coefficient $g_{Inh,r,j}$ for radionuclide r and inhalation dose coefficient $g_{Inh,j}$ of the radionuclide mixture for reference person j

Radionuclide	$g_{Inh,r,j}$ and $g_{Inh,j}$, Sv Bq^{-1}		
	12 - 17 a	> 17 a	worker[1)]
^{238}U-series:			
^{238}U	$3.4 \cdot 10^{-6}$	$2.9 \cdot 10^{-6}$	$1.6 \cdot 10^{-6}$
^{234}U	$4.2 \cdot 10^{-6}$	$3.5 \cdot 10^{-6}$	$2.1 \cdot 10^{-6}$
^{230}Th	$1.5 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$	$7.2 \cdot 10^{-6}$
^{226}Ra	$4.5 \cdot 10^{-6}$	$3.5 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$
^{210}Pb	$1.3 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$
^{210}Po	$4.0 \cdot 10^{-6}$	$3.3 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$
^{235}U-series:			
^{235}U	$3.7 \cdot 10^{-6}$	$3.1 \cdot 10^{-6}$	$1.8 \cdot 10^{-6}$
^{231}Pa	$1.5 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	$8.9 \cdot 10^{-5}$
^{227}Ac	$5.6 \cdot 10^{-4}$	$5.5 \cdot 10^{-4}$	$6.3 \cdot 10^{-4}$
^{232}Th-series:			
^{232}Th	$2.5 \cdot 10^{-5}$	$2.5 \cdot 10^{-5}$	$1.2 \cdot 10^{-5}$
^{228}Ra	$4.4 \cdot 10^{-6}$	$2.6 \cdot 10^{-6}$	$1.7 \cdot 10^{-6}$
^{228}Th	$4.7 \cdot 10^{-5}$	$4.0 \cdot 10^{-5}$	$3.2 \cdot 10^{-5}$
Mixture	$6.8 \cdot 10^{-5}$	$6.3 \cdot 10^{-5}$	$5.0 \cdot 10^{-5}$

Note:

The dose coefficients for the mixture only include the ^{238}U-series and the ^{235}U-series and were calculated assuming a natural activity ratio of the two mentioned decay chains in radioactive equilibrium of 20:1 given by:

$$g_{Inh,j} = g_{Inh,U-238,j} + g_{Inh,U-234,j} + g_{Inh,Th-230,j} + g_{Inh,Ra-226,j} + g_{Inh,Pb-210,j} + g_{Inh,Po-210,j} + \\ + 0.05 \cdot \left(g_{Inh,U-235,j} + g_{Inh,Pa-231,j} + g_{Inh,Ac-227,j}\right)$$

[1] AMAD = 5 µm.

ANNEX III PARAMETERS TO CALCULATE INTERNAL RADIATION EXPOSURE FROM INHALATION OF ^{222}Rn AND ITS SHORT-LIVED DECAY PRODUCTS

Table III.1

Dose conversion coefficients[1)] for reference person j:

- $g_{pot(Rn-222),j}$ for the potential alpha energy exposure of short-lived ^{222}Rn-decay products
- $g_{EEC(Rn-222),j}$ for the product of the ^{222}Rn exposure and the equilibrium factor

Reference person	Dose conversion coefficients	
	$g_{pot(Rn-222),j}$ [Sv m^3 J^{-1} h^{-1}]	$g_{EEC(Rn-222),j}$ [Sv m^3 Bq^{-1} h^{-1}]
≤ 1 a	1.1	$6.1 \cdot 10^{-9}$
1 - 2 a	1.1	$6.1 \cdot 10^{-9}$
2 - 7 a	1.1	$6.1 \cdot 10^{-9}$
7 - 12 a	1.1	$6.1 \cdot 10^{-9}$
12 - 17 a	1.1	$6.1 \cdot 10^{-9}$
> 17 a	1.1	$6.1 \cdot 10^{-9}$
worker	1.4	$7.8 \cdot 10^{-9}$

Table III.2

Factor $F_{Rn-222,s}$ describing the radioactive equilibrium between mining-caused ^{222}Rn and its short-lived decay products at exposure site s (equilibrium factor), dimensionless

Exposure site	Equilibrium factor $F_{Rn-222,s}$
On a mining installation or facility Indoors and outdoors	0.4
In the vicinity of a mining installation or facility Indoors and outdoors	0.4

[1] More recent developments referring to dose conversion coefficient have not been accounted for.

ANNEX IV PARAMETERS TO CALCULATE INTERNAL RADIATION EXPOSURE FROM INGESTION OF LOCALLY PRODUCED FOOD AND SOIL

Table IV.1

Ingestion dose coefficient $g_{Ing,r,j}$ for radionuclide r and ingestion dose coefficient $g_{Ing,j}$ of the radionuclide mixture for reference person j

Radionuclide	$g_{Ing,r,j}$ and $g_{Ing,j}$ [Sv Bq^{-1}]			
	≤ 1 a	1 - 2 a	2 - 7 a	7 - 12 a
^{238}U-series:				
^{238}U	$3.4 \cdot 10^{-7}$	$1.2 \cdot 10^{-7}$	$8.0 \cdot 10^{-8}$	$6.8 \cdot 10^{-8}$
^{234}U	$3.7 \cdot 10^{-7}$	$1.3 \cdot 10^{-7}$	$8.8 \cdot 10^{-8}$	$7.4 \cdot 10^{-8}$
^{230}Th	$4.1 \cdot 10^{-6}$	$4.1 \cdot 10^{-7}$	$3.1 \cdot 10^{-7}$	$2.4 \cdot 10^{-7}$
^{226}Ra	$4.7 \cdot 10^{-6}$	$9.6 \cdot 10^{-7}$	$6.2 \cdot 10^{-7}$	$8.0 \cdot 10^{-7}$
^{210}Pb	$8.4 \cdot 10^{-6}$	$3.6 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	$1.9 \cdot 10^{-6}$
^{210}Po	$2.6 \cdot 10^{-5}$ $(5.2 \cdot 10^{-6})$[1)]	$8.8 \cdot 10^{-6}$ $(1.8 \cdot 10^{-6})$[1)]	$4.4 \cdot 10^{-6}$ $(8.8 \cdot 10^{-7})$[1)]	$2.6 \cdot 10^{-6}$ $(5.2 \cdot 10^{-7})$[1)]
^{235}U-series:				
^{235}U	$3.5 \cdot 10^{-7}$	$1.3 \cdot 10^{-7}$	$8.5 \cdot 10^{-8}$	$7.1 \cdot 10^{-8}$
^{231}Pa	$1.3 \cdot 10^{-5}$	$1.3 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$	$9.2 \cdot 10^{-7}$
^{227}Ac	$3.3 \cdot 10^{-5}$	$3.1 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$
^{232}Th-series:				
^{232}Th	$4.6 \cdot 10^{-6}$	$4.5 \cdot 10^{-7}$	$3.5 \cdot 10^{-7}$	$2.9 \cdot 10^{-7}$
^{228}Ra	$3.0 \cdot 10^{-5}$	$5.7 \cdot 10^{-6}$	$3.4 \cdot 10^{-6}$	$3.9 \cdot 10^{-6}$
^{228}Th	$3.7 \cdot 10^{-6}$	$3.7 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$	$1.5 \cdot 10^{-7}$
Mixture	$4.6 \cdot 10^{-5}$ $(2.5 \cdot 10^{-5})$[2)]	$1.4 \cdot 10^{-5}$ $(7.2 \cdot 10^{-6})$[2)]	$7.9 \cdot 10^{-6}$ $(4.4 \cdot 10^{-6})$[2)]	$5.8 \cdot 10^{-6}$ $(3.7 \cdot 10^{-6})$[2)]

[1] Dose coefficient for ^{210}Po to determine radiation exposure of members of the public due to soil ingestion.
[2] Dose coefficient for the mixture when determining radiation exposure of members of the public due to soil ingestion.

Table IV.1 (continued)

Ingestion dose coefficient $g_{Ing,r,j}$ for radionuclide r and ingestion dose coefficient $g_{Ing,j}$ of the radionuclide mixture for reference person j

Radionuclide	$g_{Ing,r,j}$ and $g_{Ing,j}$ [Sv Bq^{-1}]		
	12 - 17 a	> 17 a	worker
^{238}U-series:			
^{238}U	$6.7 \cdot 10^{-8}$	$4.5 \cdot 10^{-8}$	$4.4 \cdot 10^{-8}$
^{234}U	$7.4 \cdot 10^{-8}$	$4.9 \cdot 10^{-8}$	$4.9 \cdot 10^{-8}$
^{230}Th	$2.2 \cdot 10^{-7}$	$2.1 \cdot 10^{-7}$	$2.1 \cdot 10^{-7}$
^{226}Ra	$1.5 \cdot 10^{-6}$	$2.8 \cdot 10^{-7}$	$2.8 \cdot 10^{-7}$
^{210}Pb	$1.9 \cdot 10^{-6}$	$6.9 \cdot 10^{-7}$	$6.8 \cdot 10^{-7}$
^{210}Po	$1.6 \cdot 10^{-6}$ ($3.2 \cdot 10^{-7}$)[1)]	$1.2 \cdot 10^{-6}$ ($2.4 \cdot 10^{-7}$)[1)]	$2.4 \cdot 10^{-7}$
^{235}U-series:			
^{235}U	$7.0 \cdot 10^{-8}$	$4.7 \cdot 10^{-8}$	$4.6 \cdot 10^{-8}$
^{231}Pa	$8.0 \cdot 10^{-7}$	$7.1 \cdot 10^{-7}$	$7.1 \cdot 10^{-7}$
^{227}Ac	$1.2 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$
^{232}Th-series:			
^{232}Th	$2.5 \cdot 10^{-7}$	$2.3 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$
^{228}Ra	$5.3 \cdot 10^{-6}$	$6.9 \cdot 10^{-7}$	$6.7 \cdot 10^{-7}$
^{228}Th	$9.4 \cdot 10^{-8}$	$7.2 \cdot 10^{-8}$	$7.0 \cdot 10^{-8}$
Mixture	$5.5 \cdot 10^{-6}$ ($4.2 \cdot 10^{-6}$)[2)]	$2.6 \cdot 10^{-6}$ ($1.6 \cdot 10^{-6}$)[2)]	$1.6 \cdot 10^{-6}$

Note:

The dose coefficients for the mixture only include the ^{238}U-series and the ^{235}U-series and were calculated assuming a natural activity ratio of the two mentioned decay chains in radioactive equilibrium of 20:1 given by:

$$g_{Ing,j} = g_{Ing,U-238,j} + g_{Ing,U-234,j} + g_{Ing,Th-230,j} + g_{Ing,Ra-226,j} + g_{Ing,Pb-210,j} + g_{Ing,Po-210,j} + \\ + 0.05 \cdot \left(g_{Ing,U-235,j} + g_{Ing,Pa-231,j} + g_{Ing,Ac-227,j}\right)$$

---

[1] Dose coefficient for ^{210}Po to determine radiation exposure of members of the public due to direct soil ingestion.
[2] Dose coefficient for the mixture when determining radiation exposure of members of the public due to direct soil ingestion.

Table IV.2

Annual consumption $U_{n,j}$ of reference person j for several foodstuffs n

Foodstuff	Annual consumption $U_{n,j}$ [kg]					
	≤ 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 -17 a	> 17 a
Drinking water[1)]	55	100	100	150	200	350
Fish (freshwater)	0.5	3	3	4.5	5	7.5
Processed milk products[2)] oder breast milk[3)]	200	-	-	-	-	-
Milk (including milk products)	45	160	160	170	170	130
Meat (including meat products)	5	13	50	65	80	90
Vegetable products	75	138	227	259	271	253
thereof:						
Cereals, cereal products	12	30	80	95	110	110
Fresh fruit, fruit poducts, juice	25	45	65	65	60	35
Potatoes, root vegetables, juice	30	40	45	55	55	55
Leafy vegetables	3	6	7	9	11	13
Vegetables, vegetable products, juice	5	17	30	35	35	40

[1] Quantities in [L].
[2] Another 160 L a^{-1} are added to the infant's annual drinking water quantity of 55 L a^{-1} when it is assumed that the infant is not being breastfed but is only given processed milk products that have been produced outside the region and can be considered uncontaminated. It is assumed that 0.2 kg concentrate (equivalent to 1 L milk) are dissolved in 0.8 L of water.
[3] To be accounted for alternatively (see Part I, Para. 2.6.4 d).

Table IV.3

Transfer factors $T_{n,r}$ for pasture plants and food as well as concentration factors $T_{Fi,r}$ for fish related to radionuclide r

Element	$T_{PP,r}$ [1]	$T_{LV,r}$; $T_{Pl,r}$ [1]	$T_{Mi,r}$	$T_{Me,r}$	$T_{BM,r}$	$T_{BM,Inh,r}$	$T_{Fi,r}$
	[Bq kg^{-1}(FM) / Bq kg^{-1}(DM)]		[d kg^{-1}]	[d kg^{-1}]	[d kg^{-1}]	[d kg^{-1}]	[L kg^{-1}]
U	$3 \cdot 10^{-3}$	$3 \cdot 10^{-3}$	$5 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$2 \cdot 10^{-2}$	$1 \cdot 10^{-1}$	2
Pa	$3 \cdot 10^{-3}$	$3 \cdot 10^{-3}$	$5 \cdot 10^{-6}$	$5 \cdot 10^{-3}$	$6 \cdot 10^{-4}$	$2 \cdot 10^{-1}$	30
Th	$2 \cdot 10^{-3}$	$5 \cdot 10^{-4}$	$5 \cdot 10^{-6}$	$2 \cdot 10^{-4}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	30
Ac	$3 \cdot 10^{-3}$	$3 \cdot 10^{-3}$	$2 \cdot 10^{-5}$	$3 \cdot 10^{-3}$	$6 \cdot 10^{-4}$	$4 \cdot 10^{-1}$	30
Ra	$1 \cdot 10^{-2}$	$5 \cdot 10^{-3}$	$3 \cdot 10^{-3}$	$9 \cdot 10^{-4}$	$2 \cdot 10^{-1}$	$2 \cdot 10^{-1}$	10
Pb	$1 \cdot 10^{-2}$	$7 \cdot 10^{-3}$	$3 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$2 \cdot 10^{-1}$	$1 \cdot 10^{-1}$	60
Po	$1 \cdot 10^{-2}$	$5 \cdot 10^{-3}$	$3 \cdot 10^{-4}$	$5 \cdot 10^{-3}$	$6 \cdot 10^{-1}$	$2 \cdot 10^{-1}$	300

[1] These transfer factors account for the uptake of radionuclides not only via roots but also via surface plant components due to local contamination.

Table IV.4

Values to calculate the radionuclide transport

Symbol	Definition	Value
f_p	Fraction of time per year spent on the pasture by grazing animals	0.5
f_w	Fraction of activity deposited on the plant during spray irrigation	0.3
L	Daily water consumption by cattle	75 L d^{-1}
M_{Fo}	Daily ingestion of pasture forage (FM)	65 kg d^{-1}
M_{Soil}	Daily soil ingestion by cattle when grazing on the pasture (DM)	0.5 kg d^{-1}
p_n	Proportion of local food production	
	n = Mi, Me, Fi, LV,Ve, RV, Fr	0.5
	n = W, BM, PM	1
$t_{n,e}$	Contamination time for plants during the growth period	
	n = Pl for vegetable poducts except for leafy vegetables (60 days)	$5.2 \cdot 10^6$ s
	n = LV for leafy vegetables (60 days)	$5.2 \cdot 10^6$ s
	n = PP for pasture plants (30 days)	$2.6 \cdot 10^6$ s
$t_{n,w}$	Time of surface contamination of plants due to spray irrigation during the growth period	
	n = PP: time until the same piece of pasture is fed down again (30 days)	$2.6 \cdot 10^6$ s
	n = Pl and n = LV: average growing period of vegetable products except for leafy vegetables, and of leafy vegetables, respectively (60 days)	$5.2 \cdot 10^6$ s

Table V.4 (continued)

Symbol	Definition	Value
W	Spray irrigation rate during grazing time and growth period of vegeable products (1 L m^{-2} d^{-1})	$1.2 \cdot 10^{-5}$ L m^{-2} s^{-1}
Y_n	Yield or vegetation density (FM)	
	n = LV yield of leafy vegetables	1.6 kg m^{-2}
	n = Pl yield of vegetable procucts except for leafy vegetables	2.4 kg m^{-2}
	n = PP plant cover density of pasture plants	0.85 kg m^{-2}
$\lambda_{eff,Pl,r}$	Effective rate constant for the retention of radionuclide r on the plant $\lambda_{eff,Pl,r} = \lambda_V + \lambda_r$	
λ_r	Physical decay constant of radionuclide r, s^{-1}	
λ_V	Residence constant for the retention of the radionuclides on the plant (residence time 14 days)	$5.7 \cdot 10^{-7}$ s^{-1}

Table IV.5

Soil uptake rate $U_{Soil,j}$ of reference person j

Reference person	Soil uptake rate $U_{Soil,j}$ [kg h^{-1}]
≤ 1 a	0
1 - 2 a	$5 \cdot 10^{-5}$
2 - 7 a	$3 \cdot 10^{-5}$
7 - 12 a	$6 \cdot 10^{-6}$
12 - 17 a	$6 \cdot 10^{-6}$
> 17 a	$6 \cdot 10^{-6}$
Worker	$6 \cdot 10^{-6}$

ANNEX V GENERAL LEVELS OF NATURAL ENVIRONMENTAL RADIOACTIVITY

Table V.1 (referring to Part II, Para 1)

Ambient dose equivalent rate of natural gamma radiation outdoors

The average value of ambient dose equivalent rate $H^{*}(10)^{U}$ outdoors applicable for regions with enhanced natural radioactivity at a height of 1 m is 120 nSv h^{-1}. This value includes the contribution of cosmic radiation.

Table V.2 (referring to Part II, Para 2)

General values of natural background activity concentration $C^{U}_{Air,r}$ for a particle-bound radionuclide r

Radionuclide	$C^{U}_{Air,r}$ [Bq m^{-3}]
^{238}U-series:	
^{238}U	$1 \cdot 10^{-5}$
^{234}U	$1 \cdot 10^{-5}$
^{230}Th	$1 \cdot 10^{-5}$
^{226}Ra	$1 \cdot 10^{-5}$
^{210}Pb	$3.1 \cdot 10^{-4}$
^{210}Po	$4 \cdot 10^{-5}$
^{235}U-series:	
^{235}U	$5 \cdot 10^{-7}$
^{231}Pa	$5 \cdot 10^{-7}$
^{227}Ac	$5 \cdot 10^{-7}$
^{232}Th-series:	
^{232}Th	$8 \cdot 10^{-6}$
^{228}Ra	$8 \cdot 10^{-6}$
^{228}Th	$8 \cdot 10^{-6}$
LLA[1)]	$8 \cdot 10^{-5}$

Notes:

The values for $C^{U}_{Air,r}$ were calculated from the values of activity concentration in the upper soil layer given in Table V.4 assuming a dust concentration of 50 µg m^{-3}. By reason of the radioactive decay of ^{222}Rn in the atmosphere, account was taken of an additional natural activity concentration of 300 µBq m^{-3} and 30 µBq m^{-3} for the radionuclide ^{210}Pb or ^{210}Po, respectively.

The natural background for long-lived alpha activity is the sum of natural background concentrations of the nuclides ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra and ^{210}Po.

[1] Long-lived alpha activity.

Table V.3 (referring to Part II, Para 3)

^{222}Rn concentration or potential alpha energy concentration of the short-lived ^{222}Rn decay products of the natural background outdoors

Quantity	Value
^{222}Rn concentration $\left(C^{U}_{Rn-222}\right)$	10 Bq m^{-3}
Potential alpha energy concentration of short-lived ^{222}Rn decay products $\left(C^{U}_{pot(Rn-222)}\right)$	$2.22 \cdot 10^{-8}$ J m^{-3}

Note:

The value of potential alpha energy concentration of the short-lived ^{222}Rn decay products was calculated from the ^{222}Rn concentration using an equilibrium factor of 0.4.

Table V.4 (referring to Part II, Para 4)

General values of natural background activity concentration $C^U_{n,r}$ of radionuclide r in foodstuff n

Radionuclide	$C^U_{n,r}$ [Bq kg^{-1}] (drinking water [Bq L^{-1}])					
	drinking water	milk	meat	fish	leafy vege-tables	vege-tables
^{238}U-series:						
^{238}U	$3.0 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-3}$
^{234}U	$5.0 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-3}$
^{230}Th	$1.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$
^{226}Ra	$5.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	$8.0 \cdot 10^{-3}$	$7.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-2}$	$1.0 \cdot 10^{-2}$
^{210}Pb	$2.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$	$1.5 \cdot 10^{-1}$	$3.0 \cdot 10^{-2}$
^{210}Po	$1.5 \cdot 10^{-3}$	$1.0 \cdot 10^{-2}$	$1.0 \cdot 10^{-1}$	$1.5 \cdot 10^{-1}$	$1.5 \cdot 10^{-1}$	$3.0 \cdot 10^{-2}$
^{235}U-series:						
^{235}U	$1.5 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	$5.0 \cdot 10^{-5}$	$2.0 \cdot 10^{-4}$	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
^{231}Pa	$1.5 \cdot 10^{-4}$	$1.0 \cdot 10^{-6}$	$5.0 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
^{227}Ac	$1.5 \cdot 10^{-4}$	$5.0 \cdot 10^{-6}$	$4.0 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
^{232}Th-series:						
^{232}Th	$1.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$
^{228}Ra	$4.5 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	$8.0 \cdot 10^{-3}$	$7.0 \cdot 10^{-3}$	$6.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$
^{228}Th	$1.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$

Table V.4 (referring to Part II, Para 4) (continued)

General vaules of natural background activity concentration $C^U_{n,r}$ of radionuclide r in foodstuff n

Radionuclide	$C^U_{n,r}$ [Bq kg^{-1}]		
	Cereal	Fruit	Root vege-tables
^{238}U-series:			
^{238}U	$1.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$
^{234}U	$1.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$
^{230}Th	$1.0 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-3}$
^{226}Ra	$1.5 \cdot 10^{-1}$	$1.5 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$
^{210}Pb	$4.0 \cdot 10^{-1}$	$4.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$
^{210}Po	$4.0 \cdot 10^{-1}$	$4.0 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$
^{235}U-series:			
^{235}U	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
^{231}Pa	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
^{227}Ac	$5.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
^{232}Th-series:			
^{232}Th	$1.0 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-3}$
^{228}Ra	$1.5 \cdot 10^{-1}$	$1.5 \cdot 10^{-2}$	$3.0 \cdot 10^{-2}$
^{228}Th	$1.0 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$	$5.0 \cdot 10^{-3}$

Table V.5 (referring to Part II, Para 2, 5 and 6)

General values of natural background activity concentration $C^{U}_{Soil,r}$ of radionuclide r in the upper soil layer (0 – 10 cm for pasture soil, 0 – 30 cm for arable and garden soil, 0 – 30 cm for calculating external radiation exposure) and of activity concentrations $C^{U}_{Soil(0.02),r}$ in the dust fraction and $C^{U}_{Soil(0.5),r}$ in the fine grain fraction of soil (dry mass)

Radionuclide	$C^{U}_{Soil,r}$ [Bq kg^{-1}]	$C^{U}_{Soil(0.02),r}$ [Bq kg^{-1}]	$C^{U}_{Soil(0.5),r}$ [Bq kg^{-1}]
^{238}U-series:			
^{238}U	50	200	100
^{234}U	50	200	100
^{230}Th	50	200	100
^{226}Ra	50	200	100
^{210}Pb	50	200	100
^{210}Po	50	200	100
^{235}U-series:			
^{235}U	2	8	4
^{231}Pa	2	8	4
^{227}Ac	2	8	4
^{232}Th-series:			
^{232}Th	40	160	80
^{228}Ra	40	160	80
^{228}Th	40	160	80

Notes:

The value $C^{U}_{Soil,r}$ for the radionuclide ^{226}Ra was determined by measurements. For all other radionuclides of the ^{238}U-series and the ^{235}U-series, the values for $C^{U}_{Soil,r}$ were calculated from $C^{U}_{Soil,Ra-226}$, assuming that both decay chains are in radioactive equilibrium and that the natural activity ratio exists between ^{238}U and ^{235}U.

The value $C^{U}_{Soil,r}$ for the radionuclide ^{232}Th was determined by measurements. For the other radionuclides of the ^{232}Th-series, the values for $C^{U}_{Soil,r}$ were calculated from $C^{U}_{Soil,Th-232}$ assuming radioactive equilibrium.

The values $C^{U}_{Soil(0.02),r}$ and $C^{U}_{Soil(0.5),r}$ were calculated from $C^{U}_{Soil,r}$ for all radionuclides using the concentration factors $CF_{0.02,r} = 4$ (see equation 2.1b) and $CF_{0.5,r} = 2$ (see equation 5.1a).

Table V.6 (referring to Part II, Para 6)

General values of natural background activity concentration $C_{n,r}^{U}$ of the radionuclide r in surface water (n = SurW), in spray irrigation water (n = Irr) and in cattle watering trough water (n = CW)

Radionuclide	$C_{n,r}^{U}$ [Bq L^{-1}]
^{238}U-series:	
^{238}U	$3.0 \cdot 10^{-3}$
^{234}U	$5.0 \cdot 10^{-3}$
^{230}Th	$1.0 \cdot 10^{-3}$
^{226}Ra	$5.0 \cdot 10^{-3}$
^{210}Pb	$2.0 \cdot 10^{-3}$
^{210}Po	$1.5 \cdot 10^{-3}$
^{235}U-series:	
^{235}U	$1.5 \cdot 10^{-4}$
^{231}Pa	$1.5 \cdot 10^{-4}$
^{227}Ac	$1.5 \cdot 10^{-4}$
^{232}Th-series:	
^{232}Th	$1.0 \cdot 10^{-3}$
^{228}Ra	$4.5 \cdot 10^{-3}$
^{228}Th	$1.0 \cdot 10^{-3}$

Table V.7 (referring to Part II, Para 6)

General values of natural background activity concentration $C^{U}_{PP,r}$ of radionuclide r in pasture plants (fresh mass)

Radionuclide	$C^{U}_{PP,r}$ [Bq kg^{-1}(FM)]
^{238}U-series:	
^{238}U	$1.0 \cdot 10^{-2}$
^{234}U	$1.0 \cdot 10^{-2}$
^{230}Th	$5.0 \cdot 10^{-3}$
^{226}Ra	$4.0 \cdot 10^{-2}$
^{210}Pb	$1.5 \cdot 10^{-1}$
^{210}Po	$1.5 \cdot 10^{-1}$
^{235}U-series:	
^{235}U	$5.0 \cdot 10^{-4}$
^{231}Pa	$5.0 \cdot 10^{-4}$
^{227}Ac	$5.0 \cdot 10^{-4}$
^{232}Th-series:	
^{232}Th	$4.0 \cdot 10^{-3}$
^{228}Ra	$6.0 \cdot 10^{-2}$
^{228}Th	$4.0 \cdot 10^{-3}$

Tabelle V.8 (referring to Part II, Para 6)

General values of natural background soil contamination rate $\dot{B}_r^U$ of radionuclide r from dry dust deposition

Radionuclide	$\dot{B}_r^U$ [Bq m^{-2} s^{-1}]
^{238}U-series:	
^{238}U	$1 \cdot 10^{-7}$
^{234}U	$1 \cdot 10^{-7}$
^{230}Th	$1 \cdot 10^{-7}$
^{226}Ra	$1 \cdot 10^{-7}$
^{210}Pb	$3 \cdot 10^{-6}$
^{210}Po	$4 \cdot 10^{-7}$
^{235}U-series:	
^{235}U	$5 \cdot 10^{-9}$
^{231}Pa	$5 \cdot 10^{-9}$
^{227}Ac	$5 \cdot 10^{-9}$
^{232}Th-series:	
^{232}Th	$8 \cdot 10^{-8}$
^{228}Ra	$8 \cdot 10^{-8}$
^{228}Th	$8 \cdot 10^{-8}$

ANNEX VI SIMPLIFIED PROCEDURE TO TEST THE EXEMPTION CRITERION ACCORDING TO PART I, PARA 2.3.2 a)

VI.1 TEST PROCEDURE FOR MUTIPLE SOURCES ACCORDING TO PART I, PARA 2.6.5.3 b)

For a site with n mining installations and facilities, the exemption criterion under Part I, Para 2.3.2 a) shall be deemed to be fulfilled for all exposure sites s, if the ^{222}Rn concentration determined according to equation (A1.1a), (A1.1b) or (A1.1c) does not exceed the value of 5 Bq m^{-3}. Part I, Para 2.6.5.4 shall be observed.

a)

The following equation shall apply, if exposure site s is situated in the vicinity but outside of mining installation and facility i:

$$C_{Rn-222,s} = 377 \cdot \sum_{i=1}^{n} Q_{Rn-222,i} \cdot \left(\frac{a_i}{r_{i,s}} \right)^{1.58} \qquad \text{(A1.1a)}$$

where:

$C_{Rn-222,s}$	Mean ^{222}Rn concentration at exposure site s [Bq m^{-3}]
$Q_{Rn-222,i}$	Mean ^{222}Rn emission rate of mining installation or facility i [kBq s^{-1}], see Annex VI, Para 1.1
$r_{i,s}$	Distance of exposure site s to the nearest border of mining installation or facility i [m] ($r_{i,s} \geq 20$ m)
a_i	Correction factor to allow for the meteorologic and topographic site conditions of mining installations or facilities i and for the deviation from point source geometry, dimensionless, see Annex VI, Para 1.2
n	Number of mining installations or facilities

b)

If exposure site s is directly situation on mining installation or facility i, then the following equations apply:

For flat ground:

$$C_{Rn-222,s,i} = 11 \cdot \left(J_{Rn-222,i} - J^{U}_{Rn-222}\right) \cdot \ln\left(1 + 1.7 \cdot F_i\right) + 377 \cdot \sum_{\substack{i'=1 \\ i' \neq i}}^{n} Q_{Rn-222,i'} \cdot \left(\frac{a_{i'}}{r_{i',s}}\right)^{1.58} \qquad \text{(A1.1b)}$$

Für mountainous ground:

$$C_{Rn-222,s,i} = 377 \cdot \left\{ Q_{Rn-222,i} \cdot \left(\frac{a_i}{20}\right)^{1.58} + \sum_{\substack{i'=1 \\ i' \neq i}}^{n} Q_{Rn-222,i'} \cdot \left(\frac{a_{i'}}{r_{i',s}}\right)^{1.58} \right\} \qquad \text{(A1.1c)}$$

Except for those already defined, the above symbols represent:

$J_{Rn-222,i}$ Mean ^{222}Rn exhalation rate of mining installation or facility i [Bq m^{-2} s^{-1}]

J^{U}_{Rn-222} ^{222}Rn exhalation rate of the natural background at the site [Bq m^{-2} s^{-1}]

(If $J_{Rn-222,i}$ solely includes the mining-caused fraction by reason of model calculations or use of equations (A1.3) or (A1.4), then $J^{U}_{Rn-222} \equiv 0$.)

F_i Area of mining installation or facility i [ha]

VI.1.1 CALCULATION OF THE ^{222}Rn EMISSION RATE Q_I

For areal mining installation or facility i, the ^{222}Rn emission rate $Q_{Rn-222,i}$ in equations (A1.1a), (A1.1b) and (A1.1c) can be calculated from the ^{222}Rn exhalation rate $J_{Rn-222,i}$ of mining installation or facility i as follows:

$$Q_{Rn-222,i} = 10 \cdot \left(J_{Rn-222,i} - J^{U}_{Rn-222}\right) \cdot F_i \qquad \text{(A1.2)}$$

where:

$Q_{Rn-222,i}$ Mean ^{222}Rn emission rate of mining installation or facility i [kBq s^{-1}]

$J_{Rn-222,i}$ Mean ^{222}Rn exhalation rate of mining installation or facility i [Bq m^{-2} s^{-1}]

J^{U}_{Rn-222} — ^{222}Rn exhalation rate of natural background at the site [Bq m^{-2} s^{-1}]
(If $J_{Rn-222,i}$ solely includes the mining-caused fraction by reason of model calculations or use of equations (A1.3) or (A1.4), then $J^{U}_{Rn-222} \equiv 0$.)

F_i — Area of mining installation or facility i [ha]

Notes:

a)

The mean ^{222}Rn exhalation rate $J_{Rn-222,i}$ for mine dump i can be estimated as follows from the mean ^{226}Ra activity concentration of the dump material using a conversion factor:

$$J_{Rn-222,i} = \left(C_{Ra-226,i} - C^{U}_{Ra-226}\right) \cdot b_i \qquad \text{(A1.3)}$$

where

$C_{Ra-226,i}$ — Mean ^{226}Ra activity concentration of the material of mine dump i [Bq g^{-1}]

C^{U}_{Ra-226} — ^{226}Ra activity concentration of natural background in the soil at the site [Bq g^{-1}].
(If $C_{Ra-226,i}$ solely includes the mining-caused fraction by reason of model calculations or use of equation (A1.4), then $C^{U}_{Ra-226} \equiv 0$.)

b_i — Conversion factor to estimate the ^{222}Rn exhalation rate from the ^{226}Ra activity concentration of the material of mine dump i for different types and thicknesses H of dumps [(Bq m^{-2} s^{-1})/(Bq g^{-1})]

The following values apply for b_i:

H [m]	Conversion factor b_i [(Bq m^{-2} s^{-1})/(Bq g^{-1})]		
	Type 1	Type 2	Type 3
≥ 10	0.5	1	4
5 ≤ H < 10	0.5	1	2
2 ≤ H < 5	0.5	1	1
< 2	0.5 · tanh(H)	tanh(H)	tanh(H)

where:

H — Thickness of deposition [m]

Type 1 — Mine dump for which release by convection can be excluded and release by diffusion is hindered. Type 1 is usually assumed in the case of mine dumps with enhanced silt fraction.

Type 2 Mine dump for which release by diffusion is to be assumed and where release by convection makes only insignificant contributions to radon release. Type 2 is generally to be assumed in cases of sabulous mine dumps with a wide range of particle size distribution.

Type 3 Mine dump expected to exhibit not only the usual release of radon via diffusion but also a considerable radon release by convection[1)]. Type 3 is to be assumed in cases of mine dumps with a high grit-stone proportion.

b)

In the absence of measured values of ^{226}Ra activity concentration of mine dump i material, $C_{Ra,i}$ may be approximated according to the relationship

$$C_{Ra-226,i} = 2 \cdot 10^{-3} \cdot \left(\dot{H}^*(10)_i - \dot{H}^*(10)^U \right) \qquad \text{(A1.4).}$$

Equation (A1.4) may be applied provided that the activity concentrations of both the nuclides of the ^{232}Th-series and of ^{40}K in the dump material closely agree with those in the bedrock soil,

where:

$C_{Ra-226,i}$ Mean ^{226}Ra activity concentration of dump i material [Bq g^{-1}]

$\dot{H}^*(10)_i$ Ambient dose equivalent rate outdoors at a height of 1 m above the uncovered mine dump i [Sv h^{-1}]

$\dot{H}^*(10)^U$ Ambient dose equivalent rate of natural gamma radiation at the site outdoors at a height of 1 m [Sv h^{-1}]

(When the natural background is subtracted according to Part I, Para 3.2, allowance shall be made for dependence on exposure site.)

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[1] The convective air flows occurring in type 3 mine dumps are mainly caused by temperature differences between the interior of the dump and the sorrounding atmosphere. Within the mine dump, the convective motion of the air flow run towards the toe of the dump, if the temperature inside the dump is lower than that of outdoor air. If the temperature conditions are contrary, the air flow direction within the dump is reversed. Enhanced radon discharge therefore occurs primarily within the area at the toe (summer) or at the plateau (winter) of the dump. Other main discharge pathways are also possible, depending on depositional sequences connected with the erection of the whole dump. Convective air flows inside the dump extending over the slope length of the entire dump will normally only appear when the temperature inside the dump is higher or lower than the temperature outside the dump over a longer period of time.

Equation (A1.4) does not apply for Type 3 mine dumps. Furthermore, equation (A1.4) does not apply for Type 1 and Type 2 mine dumps provided with a cover shielding photon radiation.

c)

For type 3 dumps, a maximum ^{222}Rn exhalation rate $J^{max}_{Rn-222,i}$ caused by convective processes and preferentially occurring at the dump toe and plateau, may be estimated as follows: (see footnote referring to convection for Type 3-dumps under Note a) of the present Para):

$$J^{max}_{Rn-222,i} = C_{Ra-226,i} \cdot E_i \cdot \rho_i \cdot L_i \cdot \lambda_{Rn-222} \qquad \text{(A1.5)}$$

where:

$C_{Ra-226,i}$	^{226}Ra activity concentration of dump i material [Bq g^{-1}]
E_i	Emanation coefficient of the mine dump i material, dimensionless (if no mine-dump specific value is available, we obtain approximately $E = 0.2$)
ρ_i	Dry density of dump i material [g m^{-3}] (In the absence of a mine-dump specific value, we obtain approximately $\rho_i = 2 \cdot 10^6$ g m^{-3}.)
L_i	Length of convective stream path within dump i [m] (e.g. from the toe to the plateau of the dump or from the toe to the berm of the dump; if no dump specific value is available, L_i may be approximated by the slope length over the total of dump i)
λ_{Rn-222}	^{222}Rn decay constant $2{,}1 \cdot 10^{-6}$ s^{-1}

The ^{222}Rn concentration at the exposure site may only be estimated from the maximum ^{222}Rn-exhalation rate calculated from equation (A1.5), if dump-specific investigations of ^{222}Rn release behaviour in space and time are available.

VI.1.2 CALCULATION OF THE CORRECTION FACTOR

Correction factor a_i in equations (A1.1a), (A1.1b) and (A1.1c) can be calculated as follows:

$$a_i = k \cdot k_i(r,F) \qquad \text{(A1.6)}$$

where:

k	Correction factor to allow for the meteorologic and topographic site conditions of a point source, dimensionless

here:

$k = k_{Fl} = 1.25$ for flat ground

$k = k_{Mo} = 3.0$ for mountanious ground

$k_i(r,F)$ Correction factor for the deviation from point source geometry as a function of area size F and distance r of the exposure site from the nearest border of mining installation or facility i, dimensionless

Note:

The size of correction factor k_i(r,F) can be approximated by the following equation:

$$10^3 \cdot F_i \cdot \left(\frac{k_i(r,F)}{r_i}\right)^{1.58} \cdot \tan\left(\frac{\pi}{2} \cdot k_i(r,F)\right) = 1 \qquad \text{(A1.7)}$$

The correction factor k_i(r,F) approaches the value 1 or 0 with large $(r \to \infty)$ or small $(r \to 0)$ distances, respectively.

Solutions of equation (A1.7) for areas of 0.1 ha up to 100 ha and distances from 20 m to 10,000 m are illustrated in Annex VI, Fig. VI.1.

For distance r = 20 m and areas ranging from 0.1 ha to 100 ha the correction factor $k_i(r = 20\,m, F)$ may be determined by the following approximation:

$$k_i(r = 20\ m, F_i) = \begin{cases} 0.35 \cdot F_i^{-0.31} & \text{für } F_i \le 1 \text{ ha} \\ 0.35 \cdot F_i^{-0.38} & \text{für } F_i > 1 \text{ ha} \end{cases} \qquad \text{(A1.8)}$$

VI.2 TEST PROCEDURE FOR SINGLE SOURCES ACCORDING TO PART I, PARA 2.6.5.3 b)

For single sources the exemption criterion under Part I, Para 2.3.2 a) is deemed to be fulfilled when the distances of all exposure sites s to mining installation or facility i are greater than $r^*_{i,s}$, and the minimum distance $r^*_{i,s}$ is given by the following equation:

$$r^*_{i,s} = 15.4 \cdot a_i \cdot \left(Q_{Rn-222,i}\right)^{0.663} \tag{A2.1}$$

where:

$r^*_{i,s}$ Minimum distance between exposure site s, where mining-caused ^{222}Rn concentration exceeding 5 Bq m^{-3} can be excluded, to the nearest border of mining installation or facility i [m]

a_i Correction factor to allow for meteorologic and topographic site conditions of mining installation or facility i and the deviation from point source geometry, dimensionless, see Annex VI, Para 1.2

$Q_{Rn-222,i}$ Mean ^{222}Rn emission rate of mining installation or facility i [kBq s^{-1}], see Annex VI, Para 1.1

The exemption criterion under Part I, Para 2.3.2 a) is deemed to be fulfilled for all exposure sites on mining installations or facilities that suffice the following inequation:

For flat ground:

$$\left(J_{Rn-222,i} - J^U_{Rn-222}\right) \cdot \ln(1 + 1.7 \cdot F_i) \le 0.45 \tag{A2.2a}$$

For mountainous ground:

$$\left(J_{Rn-222,i} - J^U_{Rn-222}\right) \cdot F_i \cdot a_i^{1.58} = \left(J_{Rn-222,i} - J^U_{Rn-222}\right) \cdot F_i \cdot \left\{3 \cdot k_i\left(r = 20\,m, F_i\right)\right\}^{1.58} \le 0.15 \tag{A2.2b}$$

where:

$J_{Rn-222,i}$ Mean ^{222}Rn exhalation rate of mining installation or facility i [Bq $m^{-2}\,s^{-1}$]

J^U_{Rn-222} ^{222}Rn exhalation rate of the natural background at the site [Bq $m^{-2}\,s^{-1}$].
(If $J_{Rn-222,i}$ solely includes the mining-caused fraction by reason of model calculations or use of equations (A1.3) or (A1.4), then $J^U_{Rn-222} \equiv 0$.)

F_i Area of mining installation or facilty i [ha]

$k_i(r = 20\,m, F_i)$ Correction factor for the deviation of mining installation or facility i from point source geometry for r = 20 m and area size F_i, dimensionless, see Annex VI, Para 1.2

VI.3 ESTIMATING THE ^{222}Rn CONCENTRATION OUTDOORS

The test instructions under Annex VI, Paras 1 and 2 may be used to make a conservative estimate of the mining-caused ^{222}Rn concentration outdoors. Part I, Para 2.6.5.4 shall be observed.

VI.3.1 MULTIPLE SOURCES

For exposure sites on or in the vicinity of mining installations or facilities the mean ^{222}Rn concentration outdoors can be directly estimated according to equations (A1.1a), (A1.1b) and (A1.1c) in Annex VI, Para 1.

VI.3.2 SINGLE SOURCES

a)

For exposure sites s on an areal mining installation or facilty the mean ^{222}Rn concentration outdoors can be approximated as follows:

For flat ground:

$$C_{Rn-222,i} = 11 \cdot \left(J_{Rn-222,i} - J^{U}_{Rn-222}\right) \cdot \ln\left(1 + 1.7 \cdot F_i\right) \qquad \text{(A3.1)}$$

For mountainous ground:

$$C_{Rn-222,i} = 377 \cdot Q_{Rn-222,i} \cdot \left(\frac{3 \cdot k_i(r = 20\,m, F_i)}{20}\right)^{1.58} \qquad \text{(A3.2)}$$

where:

$C_{Rn-222,i}$	Mean ^{222}Rn concentration on mining installation or facility i [Bq m^{-3}]
$J_{Rn-222,i}$	Mean ^{222}Rn exhation rate of mining installation or facility i [Bq m^{-2} s^{-1}]
J^{U}_{Rn-222}	^{222}Rn exhation rate of the natural background at the site [Bq m^{-2} s^{-1}] (If $J_{Rn-222,i}$ solely includes the mining-caused fraction by reason of model calculations or use of equations (A1.3) or (A1.4), then $J^{U}_{Rn-222} \equiv 0$.)
F_i	Area of mining installation or facility i [ha]
$Q_{Rn-222,i}$	Mean ^{222}Rn emission rate of mining installation or facility i [kBq s^{-1}], see Annex VI, Para 1.1

$k_i(r = 20\,m, F_i)$ Correction factor for the deviation of mining installation or facility i from point source geometry for r = 20 m and area size F_i, dimensionless, see Annex VI, Para 1.2

b)

For exposure site s located at distance $r_{i,s}$ from the nearest border of an areal mining installation or facility i the mean ^{222}Rn concentration outdoors can be approximated as follows:

$$C_{Rn-222,s} = 377 \cdot Q_{Rn-222,i} \cdot \left(\frac{a_i}{r_{i,s}}\right)^{1.58} \qquad \text{(A3.3)}$$

$C_{Rn-222,s}$ Mean ^{222}Rn concentration in the vicinity of mining installation or facility i at exposure site s [Bq m^{-3}]

$Q_{Rn-222,i}$ Mean ^{222}Rn emission rate of mining installation or facility i [kBq s^{-1}], see Annex VI, Para 1.1

$r_{i,s}$ Distance between exposure site s and the nearest border of mining installation or facility i [m] (r ≥ 20 m)

a_i Correction factor to allow for the meteorologic and topographic site conditions of mining installation or facility i and the deviation from point source geometry, dimensionless, see Annex VI, Para 1.2

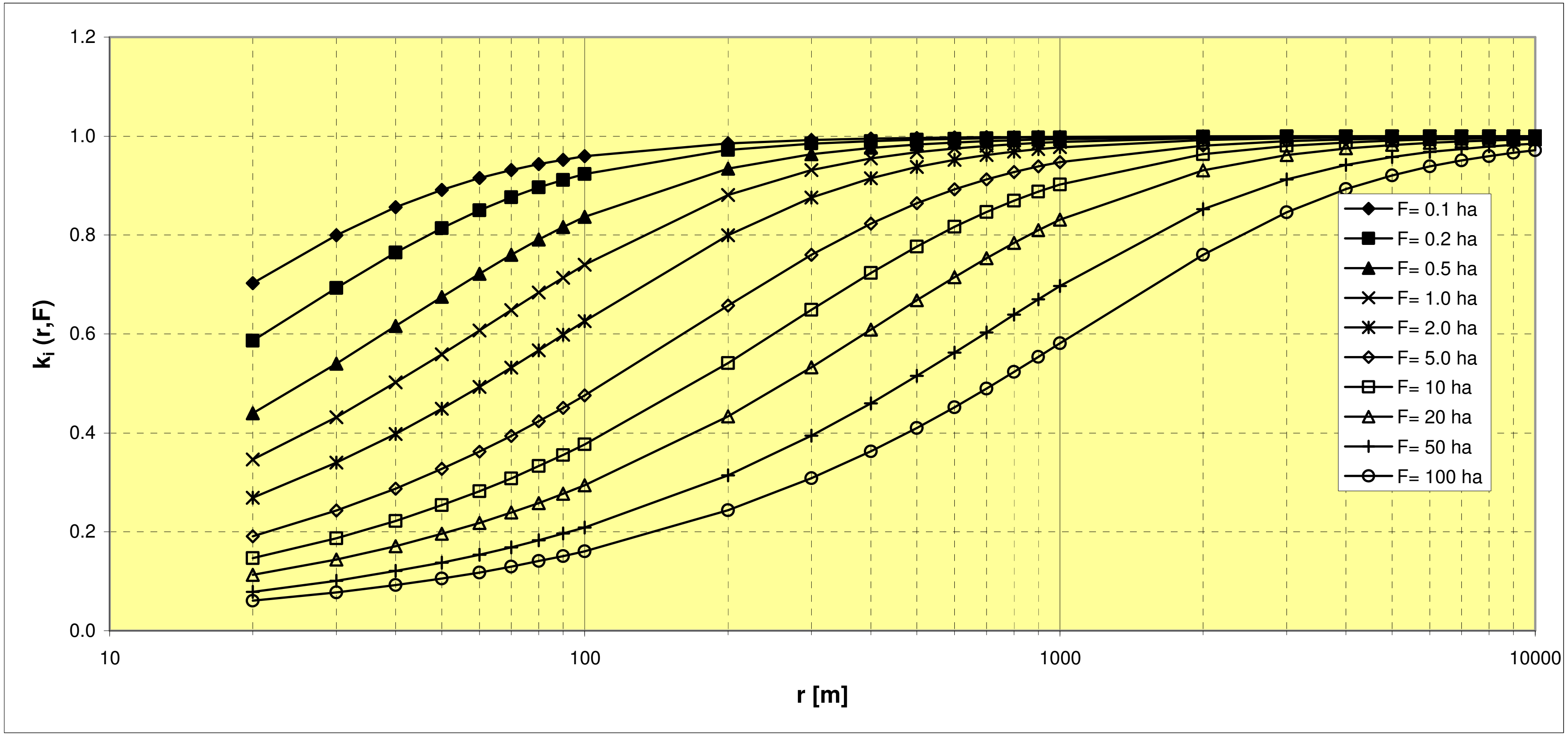

Figure VI.1

Nomogram to determine correction factor k_i (r,F) in Annex VI, Para 1.2 as a function of distance r between exposure site s and the nearest border of the area F of mining installation or facility i

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