Strahlenschutzkommission

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Operational intervention levels (OILs) for measures to protect individuals in the event of environmental contamination with alpha and beta emitters

Recommendation by the German Commission
on Radiological Protection
with scientific background

Adopted at the 279th meeting of the German Commission on Radiological Protection on 3 and 4 December 2015

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Abgeleitete Richtwerte für Maßnahmen zum Schutz von Personen bei Kontaminationen der Umwelt mit Alpha- und Betastrahlern

Empfehlung der Strahlenschutzkommission mit wissenschaftlicher Begründung

Contents

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Contents

1 Introduction

To date, investigations into accidents involving radioactive material have largely focussed on accidents involving gamma emitting radionuclides. Such accidents include those that occur at nuclear power plants as well as accidents involving sealed radioactive sources from medical and industrial applications. In such cases, exposure to alpha and beta radiation is not explicitly considered as gamma radiation largely dominates the exposure pathways and doses.

However, particularly in defence against radiological attacks, discussions are increasingly focussing on scenarios that may involve releases from sources with alpha and beta emitters which are normally sealed and shielded. Scenarios involving a potential release in an urban environment are of particular interest due to the fact that they would potentially affect a large number of people.

In its letter dated 21 January 2009, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) asked the German Commission on Radiological Protection (SSK) to produce a recommendation on operational intervention levels for alpha and beta emitting radionuclides. The BMU's letter highlighted the fact that there is a general lack of operational interventional levels for such radionuclides. Available literature only occasionally covers nuclide-specific operational intervention levels, and even then it only considers certain exposure pathways, such as inhalation of resuspended radionuclides in the catalogue of countermeasures (SSK 2007a).

To the extent literature provides operational intervention levels for measures to protect the general public and emergency services and support personnel, the corresponding doses are often not stated and the required calculation is generally not provided, either. Various sources state 100 Bq cm^{-2} for alpha contamination and 1,000 Bq cm^{-2} for beta contamination as values to be used to demarcate hazard areas (IAEA 2006, IAEA 2007, NCRP 2010, Rojas-Palma et al. 2009, Boson et al. 2014).

Incidents leading to alpha or beta contaminations give rise to a number of specific problems:

– In the absence of any accompanying gamma radiation, the dose-rate measuring devices generally used by the police and the fire brigades are unsuitable to detect any existing contaminations. The dose-rate criteria for hazard areas stipulated in German fire brigade regulation 500 (AFKzV 2012), for example, cannot be applied. To ascertain any existing contaminations, measurements are required using contamination monitoring procedures that generally take longer and are more complex to perform than dose-rate measurements.
– Nuclide-specific measurements involving, e. g. alpha spectrometry are time-consuming.
– When it comes to beta radiation, conventional radiation protection monitoring of emergency workers using dosimeters cannot be ensured due to the general lack of beta-sensitive dosimeters.
– Incidents involving radioactive contamination in an urban environment are particularly difficult to manage as a large number of people may be affected and the contamination may seriously restrict the continued use of the area, e. g. as a place of work or residence. Such cases will be covered in the following scenario.

2 Scenario

A particularly high number of people may be affected if an incident occurs in an urban environment where radionuclides are released into said environment.

The scenario portrayed here assumes that it is no longer possible to influence the source causing the incident. It is assumed that a release with subsequent contamination has taken place in an urban environment. Only releases into the air will be considered, and it is assumed that the ensuing cloud has already moved away and that depositable radionuclides have led to ground contamination[1].

3 Exposure pathways

The external radiation of radionuclides deposited on the ground in the event of beta emitting radionuclides, the inhalation of resuspended radionuclides and the ingestion of contaminated soil constituents by children are considered as exposure pathways for which operational intervention levels are to be provided. Consumption of soil is of far less importance among adults than among small children, which is why calculations pertaining to the ingestion of contaminated soil constituents were based on children (see Annex A-5 of the scientific background). However, this exposure pathway is not dominant.

Furthermore, the skin dose due to contamination of the skin and clothing should also be taken into consideration for members of the public and emergency service workers involved in decontamination and other similar work in order to initiate personal decontamination measures if required.

The ingestion pathway due to contaminated foodstuffs is not taken into consideration when defining operational intervention levels. It is assumed that warnings about consuming potentially contaminated foodstuffs will be readily heeded. Such a warning should always be issued as a precaution, irrespective of the level of contamination.

The same also applies for unintentional ingestion due to coming into contact with contaminated objects. Here it is also assumed that the potential exposure pathway should not be taken into consideration initially due to issuing corresponding warnings and conduct recommendations.

The assumption described above whereby the release has already taken place means that both direct radiation from the passing radioactive cloud and the resulting inhalation dose are no longer avoidable and therefore not included in the models developed here to calculate operational intervention levels. Only exposure from the remaining ground contamination can be avoided or reduced by taking appropriate measures.

4 Principles of radiation protection

4.1 Protection strategy

The scientific background outlines a protection strategy that can be used in the scenarios under consideration.

The aim of the protection strategy is to limit exposure to the public and emergency workers in order to avoid deterministic radiation effects and alleviate the risk of stochastic radiation effects. The operational intervention levels will provide a basis for ensuring compliance with the intervention levels set out below as well as the reference level for the residual effective dose of 100 mSv (SSK 2014) in the first year that applies to such emergency situations. The components

[1] If a release into the air has taken place, it is assumed that the ensuing cloud has already moved away and that depositable radionuclides have led to extensive ground contamination and contamination of other surfaces (hereinafter referred to as ground contamination).

of the protection strategy set out below meet the requirements stipulated in Article 73 of Directive 2013/59/Euratom (Euratom 2014). The protection strategy initially comprises the isolation of areas in which protective measures for the public are required. Under certain circumstances, this demarcation must take place in several stages:

– Precautionary cordoning off of a suspected area[2] in which measures may be required to defend against immediate hazards,

– Demarcation of the affected area[3], initially on the basis of approximate contamination measurements,

– Estimates of the size of other areas for which special conduct recommendations (such as refraining from consuming potentially contaminated foodstuffs, not permitting children to play outdoors) should be provided along with corresponding information and warnings issued to the public. Annex A 5.5 of the scientific background outlines an approach for arriving at a hazard area estimate.

Measures must then be taken to defend against any immediate hazard within the demarcated area. These measures include, for example, sheltering, limiting access, possibly evacuation and conduct recommendations (e. g. taking off outer layers of clothing before entering living areas, limiting time spent outdoors to the bare minimum).

As soon as possible, but nevertheless in a methodical manner, the contaminants should be fixed. For contaminations with alpha or beta emitting radionuclides, this may be achieved by using simple measures such as spraying the area with a mixture of water and glycerine.

If necessary, decontamination measures in accordance with the ALARA principle can be performed at a later stage.

Suitable facilities (e. g. emergency units) should be installed for monitoring contamination and – if required – for the decontamination of members of the public and emergency workers.

Each step should be conveyed to members of the public and emergency workers directly or via the media.

4.2 Intervention level

The German Commission on Radiological Protection recommends an effective dose of 10 mSv as an intervention level for initiating protective measures for the public based on the assumption of spending a period of 7 days in a contaminated area without any protection. This value was stipulated for “sheltering” based on the intervention level provided in the “Basic Radiological Principles for Decisions on Measures for the Protection of the Population against Incidents involving Releases of Radionuclides” (SSK 2014).

Measures ranging from limited stays through to evacuation are to be considered if there is a risk of the effective dose exceeding 100 mSv over a period of 7 days when unprotected. As “sheltering” can only be enforced for around 2 days, evacuation should also be considered if the above dose criterion is not expected to be reached in spite of natural processes, shielding or fixation measures.

[2] A suspected area is an area in which measures may be required to defend against immediate hazards due to potential contamination with radioactive material. The boundaries of the area have not yet been demarcated on the basis of measurements; the size of the suspected area can only be estimated unless other information provides grounds for temporary demarcation.

[3] An affected area is an area determined by means of (approximate) measurements in which measures are required to defend against immediate hazards due to the operational intervention levels having been exceeded.

4.3 Operational intervention levels (OILs)

Operational intervention levels are measurable levels that are proportional to the intervention level of the dose. Regarding alpha and beta emitters, ground contamination as activity per area is a suitable parameter that can be measured using contamination monitors. The operational intervention levels in this recommendation are provided on a nuclide-specific basis and apply to adults as representative persons.

5 Radionuclides to be considered

This recommendation shall only cover alpha or beta emitting radionuclides that can be realistically expected to occur separately and in highly concentrated form in the event of an incident. Based on this pre-selection, only the radionuclides whose long half-life require mid- to long-term measures through to sufficient decay were considered here. This means that radionuclides with a half-life of less than 1 day will not be taken into consideration as they are irrelevant when it comes to measures required in the mid- to long-term.

Gaseous radionuclides were excluded with just a single exception as they will not lead to surface contamination due to deposition. Particularly with Rn-222, the decay product of Ra-226, the decay products present up until release and, to some extent, the daughter nuclides newly formed during the integration period were included in the radiation exposure calculation. Tritium (H-3) was also left out of the radionuclide selection because it behaves differently in the environment to the radionuclides in particle form under consideration here when in its predominant chemical bonding forms. Tritium is also only slightly radiotoxic due to its low average decay energy (5.6 keV) when compared with other beta emitters.

After calculating the operational intervention levels using the specific activity of the pure radionuclide, an assessment was performed to determine the respective radionuclide mass needed to exceed the intervention level for one of the exposure pathways under consideration. With extremely long-lived radionuclides, such large masses are required that – in realistic scenarios – they can be excluded as sources of contamination to be considered here. These radionuclides have therefore been excluded from any further considerations. Despite their low specific activities, U-234, U-235 and U-238 have been retained in the selection because they are present in large quantities as uranium in its natural isotopic composition (U-nat[4]) or in enriched (U-5%[5]) or depleted form (U-dep[6]) and also because they are frequently transported. As with other heavy metals, uranium has chemotoxic effects as well as being radiotoxic. Uranium's chemotoxic effects are largely dependent upon the solubility of the chemical compound present in each case. Inhalation and – to a lesser extent – ingestion are the main

[4] Natural uranium (U-nat) is chemically separated uranium in its natural isotopic composition. A becquerel of natural uranium is equivalent to 0.489 alpha decays per second of U-238, 0.489 alpha decays per second of U-234 and 0.022 alpha decays per second of U-235. This corresponds to mass proportions of 99.275% for U-238, 0.72% for U-235 and 0.005% for U-234. U-238 is in radioactive equilibrium with its daughter nuclides Th-234 and Pa-234m after around 100 days. U-235 reaches radioactive equilibrium with its daughter nuclide Th-231 after about 10 days. From a dosimetric perspective, the radionuclides involved in these two decay chains do not require any further consideration. The same applies to all of the daughter nuclides in the U-234 decay chain. The # symbol indicates that the respective daughter nuclides of the uranium isotope are taken into account.

[5] In U-5%, the mass proportion of U-235 in the uranium mixture is enriched to 5%. In general, enrichment leads to an increase in the proportion of isotopes with a lower mass; this therefore increases the specific activity (Bq/kg) largely determined by U-234.

[6] Depleted uranium (U-dep or DU) means an increase in the proportion of U-238 and a decrease in the proportion of isotopes with a lower mass number. The specific activity is lower than that of U-nat.

exposure pathways. At the same level of incorporated activity, chemotoxic effects may in fact exceed radiotoxic effects. As a result of that, when detecting uranium, including at levels below the operational intervention levels ascertained in this recommendation, assessments are required to determine whether measures are required due to the level of chemotoxicity involved. The considerations necessary to do so do not form part of this recommendation.

A number of radionuclides in the selection under consideration form daughter nuclides that must each be taken into account when calculating the dose for the exposure pathways under consideration. In the contamination incidents covered here, the age of the parent-daughter radionuclide mixture is initially unknown. However, it is to be assumed that a certain period of time has passed between potential separation of the pure parent nuclide and the incident-related ground contamination. In order to arrive at a conservative dose estimate that includes the contributions of the daughter nuclides, the age of the radionuclide mixture was stipulated as being at a point in time in which the total radionuclide mixture activities are at their highest within a period of 10 years since the presence of the pure parent nuclide (see Annex A-1 of the scientific background).

In some cases the daughter nuclides also emit gamma radiation, which can be detected using known measurement techniques. This fact could justify the exclusion of these radionuclide chains from further considerations. However, these radionuclide chains have been retained in the selection if the alpha and/or beta radiation of the parent/daughter radionuclide mixture makes a substantial contribution (> 50 %) to the total exposure.

6 Recommendations

6.1 Operational Intervention Levels (OILs) for Measures during an Early Phase after Determining Contamination

Tables 1 and 2 contain ground contamination values in Bq m^{-2}, which can be used to demarcate an affected area and trigger measures there in order to protect the public, e. g. sheltering, access control, poss. evacuation and corresponding measures. These values are derived from an effective dose intervention level of 10 mSv with an integration period of 7 days. The calculation of these operational interventions levels is described in detail in the annex of the scientific background. Radionuclides marked with # are parent-daughter radionuclide mixtures that may deviate from the secular equilibrium. The daughter nuclides under consideration are listed individually in the scientific background.

Table 1: Operational intervention levels for ground contamination (total contamination for radionuclide mixtures) in Bq m^{-2} for beta emitters which lead to the effective dose reaching the intervention level of 10 mSv within an integration period of 7 days (most restrictive level for the exposure pathways inhalation after resuspension and external radiation of contaminated ground)

Radionuclide	Half-life*)	Operational intervention level of ground contamination in Bq m^{-2}	Dominant exposure pathway
P-32	14.3 d	2.3E+08	B
P-33	25.4 d	9.0E+10	R
S-35	87.4 d	6.8E+10	R
Ca-45	163.0 d	3.5E+10	R
Ni-63	96.0 a	9.8E+10	R

Radionuclide	Half-life*)	Operational intervention level of ground contamination in Bq m^{-2}	Dominant exposure pathway
Sr-89	50.5 d	2.5E+08	B
Sr-90#	29.1 a	3.0E+08	B
Y-90	64.0 h	3.3E+08	B
Pr-143	13.6 d	9.5E+08	B
Pm-147	2.6 a	2.6E+10	R
Er-169	9.3 d	1.5E+11	R
Tm-170	128.6 d	6.4E+08	B
Tl-204	3.8 a	1.5E+09	B
Bi-210	5.0 d	7.4E+08	B
Lowest operational intervention level		2.3E+08	B
Intervention level for beta contamination		1.0E+08	-

*) Half-life of the parent nuclide for radionuclides marked with #
R = Resuspension
B = Ground radiation

All of the operational intervention levels for ground contamination in Table 1 are well above the 1,000 Bq cm^{-2} (1.0E+07 Bq m^{-2}) level for beta emitters proposed by the IAEA (IAEA 2007). If the beta emitting radionuclide or contributing beta emitting radionuclides have not yet been identified and there are no nuclide-specific measurements available, 1.0E+08 Bq m^{-2} should be used as a basis for decisions on initial measures to be taken in the event of beta contaminations.

With the exception of (Ac-227# with 9.0E+05 Bq m^{-2}), all of the operational intervention levels for ground contamination involving alpha emitting radionuclides in Table 2 are above the 100 Bq cm^{-2} (1.0E+06 Bq m^{-2}) level for alpha emitters proposed by the IAEA. If the alpha emitting radionuclide or contributing alpha emitting radionuclides have not yet been identified, 1.0E+06 Bq m^{-2} should be used as a basis for decisions on initial measures to be taken in the event of alpha contaminations.

Table 2: Operational intervention levels for ground contamination (total contamination for radionuclide mixtures) in Bq m^{-2} for alpha emitters which lead to the effective dose reaching the intervention level of 10 mSv within an integration period of 7 days (most restrictive level for the exposure pathways inhalation after resuspension and external radiation of contaminated ground)

Radionuclide	Half-life*)	Operational intervention level of ground contamination in Bq m^{-2}	Dominant exposure pathway
Po-210	138.4 d	3.0E+07	R
Ra-223#	11.4 d	3.3E+07	R
Ra-226#	1,600 a	4.1E+07	R
Ac-225#	10.0 d	5.1E+07	R
Ac-227#	21.8 a	9.0E+05	R
Th-227#	18.7 d	2.2E+07	R
Th-228#	1.9 a	1.2E+07	R
Th-229#	7,340 a	2.5E+06	R

Radionuclide	Half-life*)	Operational intervention level of ground contamination in Bq m^{-2}	Dominant exposure pathway
U-nat#		2.4E+07	R
U-5%#		1.6E+07	R
U-dep#		3.0E+07	R
Pu-238	87.7 a	1.2E+06	R
Pu-239/Pu-240	24,065 a/6,537 a	1.1E+06	R
Am-241	432.2 a	1.3E+06	R
Cm-242	162.8 d	2.2E+07	R
Cm-244	18.1 a	2.2E+06	R
Cf-252	2.6 a	6.4E+06	R
Lowest operational intervention level		9.0E+05	R
Intervention level for alpha contamination		1.0E+06	---

*) Half-life of the parent nuclide for radionuclides marked with #
R = Resuspension

Initial indicative measurements only show whether alpha and/or beta radiation is present. If alpha radiation is detected, or if alpha and beta radiation are simultaneously detected without any nuclide identification, an alpha contamination intervention level of 1.0E+06 Bq m^{-2} should be used as a basis for decisions on initial measures. If both radiation types are simultaneously detected, it is not possible to decide whether this is radiation from one of more independent radionuclides such as Am-241 or Sr-90, or from a decay series such as that of U-238, without first identifying the nuclides. The intervention level for beta contamination should be applied if only beta radiation is present without nuclide identification.

If, at a later time, the nuclide composition of the radionuclide mixture is identified and there are indications that the contamination is a mixture of the individual or parent nuclides set out in Tables 1 and 2, compliance with the operational intervention level can be verified using the following molecular formula:

$$\sum_r \frac{B_r}{ARW_r} \leq 1$$

where

B_r is the measured contamination level for radionuclide r,
ARW_r is the operational intervention level for radionuclide r.

Here it can be seen that contaminations of large outdoor surfaces which reach the operational intervention levels in Tables 1 and 2 are only to be expected under extreme conditions.

6.2 Operational intervention levels of skin contamination to trigger personal decontamination

The effective dose is insufficient to assess an exposure due to direct contamination of the skin as a result of accidents or other unplanned radionuclide releases. Both beta emitting radionuclides and high-energy alpha emitting radionuclides could contribute to this exposure, which is why the protection strategy (Section 4.1) prescribes contamination checks and possibly subsequent personal decontamination. For this reason, criteria must be put in place that stipulate a level above which skin contaminations should then be subject to personal decontamination.

In order to derive such criteria, two exposure situations are provided (ICRP 2007, ICRP 2009a, ICRP 2009b):

a) An emergency exposure situation may affect both the general public and emergency workers. An assessment of the situation is still tentative and potential exposure may be high. Emergency workers will be required to perform measurements, contamination fixation, and support the measures being carried out to protect the public.

   There is currently no dose-related intervention level for triggering personal decontamination among the general public.

   Directive 2013/59/Euratom (Euratom 2014) defines a so-called emergency worker as any person having a defined role as a worker in an emergency who might be exposed while taking action in response to the emergency. This emergency worker should be considered an occupationally exposed individual. According to (ICRP 2007) and (Euratom 2014), the equivalent dose for the skin of emergency workers should be below 500 mSv per incident as per the limit for occupationally exposed individuals, averaged over any 1 cm^2 of skin, irrespective of the exposed area.

   According to (ICRP 2007), this can be justified with the still sizeable margin from threshold doses for deterministic effects and the low risk of stochastic effects resulting from a skin dose at this level.

b) After initial success with measures to reduce exposure (shielding, fixation, decontamination), and as a result of natural processes and more accurate insights into the radiological situation, the transition to an existing exposure situation can occur. The German Commission on Radiological Protection holds the view that this transition must be formally issued by the competent authorities as it requires sound knowledge of the radiological situation as well as a sufficiently low level of exposure in the affected area so as to result in far lower health risks (ICRP 2009a). It is then assumed that contamination monitoring and personal decontamination of the public in special facilities (emergency unit) are no longer required. However, emergency workers are still required to carry out clean-up work, additional decontamination measures and the like in order to reduce exposure as per the ALARA principle. In accordance with the ICRP statements in (ICRP 2009a), the German Commission on Radiological Protection recommends such deployments be prepared and carried out in line with the radiation protection principles for planned exposure situations.

Upon separate consideration of the two exposure situations and population groups (i.e. the general public and emergency workers), and as shown in the scientific background, nine intervention levels for personal decontamination need to be stipulated for three groups of radionuclides. Personal contamination checks and any necessary subsequent personal decontaminations will be performed in emergency units (AK V 2014, SSK 2007b). Personal decontamination is a relatively easy measure to perform (change clothes, wash or shower thoroughly) without having any negative impact on the contaminated person.

For this reason, when making decisions about decontamination measures, the German Commission on Radiological Protection follows Section 46(2) of the German Radiation Protection Ordinance (StrlSchV 2001) by recommending a low, uniform dose-related intervention level of 50 mSv for skin doses both to members of the public and emergency workers, despite the biological effect of low skin doses being deemed negligible (Preston et al. 2007). As a result, emergency workers may continue to be deployed if the derived intervention level is exceeded (see below) and if a subsequent decontamination of the workers is carried out.

During radiation protection monitoring as prescribed in (Euratom 2014), it must be ensured that a level of 500 mSv is not exceeded wherever possible.

With some alpha emitting radionuclides and their decay chains, the exposure path ingestion may lead to an ingestion dose due to a person's hand coming into contact with skin/clothing and inadvertently touching their mouth afterwards which subsequently leads to contamination. For this path, the German Commission on Radiological Protection recommends a dose-related intervention level of 1 mSv for the effective dose. If the operational intervention levels for this exposure pathway are lower than those of the external skin radiation, the ingestion dose shall be the determining factor.

The operational intervention levels for activity per area on the skin and/or clothing in Table 3 are determined on the basis of this, which, if exceeded, should trigger personal decontamination. The calculation is set out in the scientific background (Annex A-4).

Table 3: Operational intervention levels of the measured activity per area on the skin and/or clothing (in Bq cm^{-2}), which, if exceeded, should trigger personal decontamination. Basis: Dose-related dose intervention level of 50 mSv for the skin dose and 1 mSv for the effective dose due to unintentional ingestion

Exposure situation	Radionuclide group	Intervention level
Emergency exposure situation and subsequent existing exposure situation	Beta emitters other than Ac-227#	100 Bq cm^{-2}
	Alpha emitters or decay series with alpha energies of > 6.5 MeV and Ac-227#	1 Bq cm^{-2}
	Alpha emitters or decay series with alpha energies of < 6.5 MeV	1,000 Bq cm^{-2}

Alpha emitters or decay series with alpha energies of >6.5 MeV include the following radionuclides: Ra-223#, Ra-226#, Ac-225#, Ac-227#, Th-227#, Th-228#, Th-229#. The beta emitting radionuclide Ac-227# can be included in this group because the decay chains largely match those of various high-energy alpha emitters. All of the radionuclides in this group have gamma emitting daughter nuclides, but the highest skin dose contributions come from high-energy alpha emitting daughter nuclides such as Po-212, Po-213, Po-215 and At-217.

Alpha emitters or decay series with alpha energies of < 6.5 MeV include the following radionuclides and radionuclide mixtures: Po-210, Pu-238, Pu-239/Pu-240, Am-241, Cm-242, Cm-244, Cf-252, U-nat#, U-5%#, U-dep#.

Extensive knowledge of the radiological situation should be available, at the latest, upon transition from an emergency exposure situation to an existing exposure situation, if not sooner (ICRP 2009a). The intervention levels in Table 3 can, if necessary, be adjusted to the prevailing situation once the radionuclides involved have been determined.

Members of the public directly affected by measures will have highly specific questions, and will be far more likely to ask them than members of the public who are not within the area to be subject to measures. Many such questions (e. g. meaning of measured values, how to handle contaminated objects and vehicles) will be predictable and are most likely to be asked in emergency units or other similar facilities. The SSK therefore encourages the development of a communication concept in advance so that emergency and support workers in direct contact with affected members of the public are able to provide appropriate answers to such questions. A concept like this needs to designed such that emergency and support workers can be informed and instructed at very short notice.

6.3 Confirmation of exceedance of operational intervention levels

The introduction provided several insights into the problems incurred in measuring the activity per area of alpha and beta emitting radionuclides. The scientific background discusses a measurement strategy that can be applied in the presence of a contamination involving alpha and beta emitting radionuclides. This discussion also includes an overview of the four types of contamination monitors which are available to disaster control units in Germany.

The previous section described the operational intervention levels for both ground contamination and contamination of the skin and/or clothing. Overall, it should be noted that these values are at times extremely high:

The investigation into measuring devices described in the scientific background shows that it is not possible to quantitatively detect beta emitting radionuclides, even at the lowest respective intervention level for ground contamination, due to their levels significantly and subsequently exceeding the measurement range. However, correct device calibration should enable quantitative detection of alpha emitters exceeding the intervention level.

In terms of contamination measurements for triggering personal decontamination, quantitative detection of the investigated beta emitters and alpha emitters with alpha energy of > 6.5 MeV is possible with all four contamination monitors under consideration. For alpha emitters with an alpha energy of < 6.5 MeV, the operational intervention level of 1,000 Bq cm^{-2} can only be quantitatively detected by two of the contamination monitors under consideration as the measurement range is exceeded when using the other two contamination monitors.

Obviously, measuring device development has focussed on facilitating the detection of extremely small radioactive contamination and concentration levels, meaning that there are deficits when it comes to detecting high contamination and concentration levels.

For this reason, the German Commission on Radiological Protection recommends to collaborate with measuring device manufacturers, measurement institutions, professional associations and users in order to further advance considerations concerning measuring strategies to be applied here. The following targets should be the main topics of discussion:

- Quantitative detection of high contamination levels, e. g. by taking dust and swipe samples,
- Determination of availability of beta local-dose-rate measuring devices and beta-sensitive electronic personal dosimeters, e. g. in the GRS catalogue of support options[7],
- Preparation of instructions on how to handle the various measuring devices during measuring tasks to be performed during the scenario under consideration here (see Section 11 and Annex A-7 of the scientific background).

When training and instructing emergency workers, particular emphasis should be placed on highlighting the possible presence of contaminations that cannot be detected using conventional dose-rate measuring devices due to a lack of or very low level of gamma radiation.

[7] GRS (Gesellschaft für Anlagen- und Reaktorsicherheit) is a German expert organisation in the field of nuclear safety and radioactive waste management. On behalf of the German Ministry for the Environment, Nature Conservation, Building and Reactor Safety GRS maintains a catalogue of support options (listing e.g. experts, monitoring devices, decontamination facilities) which is available to the German safety authorities.

6.4 Precautionary warning

The protection strategy (Section 3.3 of the scientific background) states that contaminations cannot be ruled out to occur in an area beyond the suspected area which could lead to substantial doses via the ingestion pathway. An example of this would be the contamination of open foodstuffs due to a radioactive cloud passing by. Accordingly, a precautionary warning should be issued to the general public to tell them not to consume such foodstuffs, to avoid potentially contaminated objects and to prohibit children from playing outdoors until further notice. Distances such as those for the suspected area cannot be calculated without knowing which radionuclides are involved and what level of contamination is present.

Based on the proposal made in (IAEA 2013), the German Commission on Radiological Protection recommends initially issuing such a precautionary warning up to a distance of 8 km within a sector of 45 degrees in the cloud's drift direction.

Annex A-5.5 of the scientific background describes a method which can be used to estimate the magnitude of the area to be warned after determining an area to be subject to measures.

7 Further information

The scientific background complements this recommendation by providing further information about protective measures, how to inform the general public, how to protect emergency workers, and information about various medical aspects.

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Operational intervention levels (OILs) for measures to protect individuals in the event of environmental contamination involving alpha and beta emitters

Scientific background of the recommendation by the German Commission on Radiological Protection

Adopted at the 279th meeting of the German Commission on Radiological Protection on 3 and 4 December 2015

Contents

1 Introduction

To date, investigations into accidents involving radioactive material have largely focussed on accidents involving gamma emitting radionuclides. Such accidents include those that occur at nuclear power plants as well as accidents involving sealed radioactive sources from medical and industrial applications. In such cases, exposure to radionuclides only involving alpha and beta emitters is not explicitly considered as the gamma radiation also present generally dominates the dose.

However, particularly in defence against radiological attacks, discussions are increasingly focussing on scenarios that may involve releases from sources with alpha and beta emitters which are normally sealed and shielded. Scenarios involving a potential release in an urban environment are of particular interest due to the fact that they would potentially affect a large number of people.

Contaminations only consisting of alpha and beta emitting radionuclides are difficult to detect without using special measurement techniques. However, if they involve notable activities across various exposure pathways they can result in major detriment to health.

Even if gamma radiation is detected, a significant proportion of the exposure may in fact be caused by simultaneous alpha or beta radiation.

This gives rise to the question of potential protection and defence measures as well as suitable intervention levels for taking decisions with regard to the following points:

- How long residents are permitted to stay in an area contaminated with alpha or beta emitters,
- Up to what level of contamination emergency workers are permitted to work in the contaminated area, and what kind of contaminations should lead to the decision to evacuate the area and what reason should be given for doing so,
- When the area can be used again.

The “Radiological Bases for Decisions on Measures for the Protection of the Population against Accidental Releases of Radionuclides” (SSK 2014) are generally based on a scenario involving an accident at a nuclear power plant where the core has experienced a meltdown and subsequent release of contamination into the environment. The intervention levels for protective measures recommended in (SSK 2014) therefore refer to a radionuclide mixture largely consisting of penetrating gamma radiation, which is why their application is not expedient to the cases under discussion here.

International literature only provides few sources that investigate intervention levels for measures to be implemented in the event of widespread contaminations involving alpha or beta emitting radionuclides.

Within the context of protective measures concepts, the IAEA provides information about intervention levels for alpha and beta emitters (IAEA 2006, IAEA 2007) for creating cordoned areas in the wake of a radiological incident. Ground contamination intervention levels for demarcating an inner cordoned area are 100 Bq cm^{-2} (1 MBq m^{-2}) [8] for alpha emitters and 1,000 Bq cm^{-2} (10 MBq m^{-2}) for beta/gamma emitters. Corresponding details are also available

[8] According to (IAEA 2006), the inner cordoned area is the area around a hazardous radioactive source in which precautionary measures should be taken to protect emergency workers and the general public from potential external radiation and contamination. This definition more or less corresponds with the hazard area set out in (AFKzV 2012); if the boundaries are determined by dose rates, the cordoned area is limited to a smaller area (hazard area: 25 µSv h^{-1}, inner cordoned area: 100 µSv h^{-1}).

in the TMT handbook (Rojas-Palma et al. 2009) and NCRP Report 161 II (NCRP 2010). However, there is no indication as to which operational intervention levels and exposure levels are used as a basis for the above intervention levels (Boson et al. 2014)

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has taken up these questions and, in a letter dated 21 January 2009, asked the German Commission on Radiological Protection (SSK) to produce a recommendation on operational intervention levels for triggering measures which should also consider information provided by the Federal Office for Radiation Protection (BfS). As a result, the German Commission on Radiological Protection set up a working group consisting of members of the “Emergency Management” and “Radioecology” committees which was then tasked with drafting a recommendation.

The SSK initially investigated the following questions:

– Which scenarios should be considered?
– Which radionuclides should be considered, and what are their radiological properties?
– Which exposure pathways dominate within an urban environment and how can they be modelled?
– Which reference persons need to be considered in the various given scenarios?
– Which radiation protection principles need to be considered when recommending operational intervention levels?
– Which protective measures can be taken, which associated intervention levels are to be applied, and which operational intervention levels (measurable parameters) correspond with the intervention level(s)?

The SSK also considered the requirements in terms of measuring devices used to demarcate an affected area and looked into how emergency workers can be protected while also providing information on how to implement protective measures on a practical level.

2 Scenario

Contaminations in an urban environment with only alpha or beta emitting radionuclides may occur for various reasons such as a loss of the enclosure and distribution of radionuclides due to an accident, unintentional loss or theft without knowledge of the risks involved, distribution of radioactive material as dust and/or fragments/splinters resulting from a malicious act.

With many of these contamination incidents it is no longer possible to influence the source causing the incident. It is assumed that a release with subsequent contamination has taken place. If a release into the air has taken place, it is assumed that the ensuing cloud has already moved away and that depositable radionuclides have led to extensive ground contamination and contamination of other surfaces (hereinafter referred to as ground contamination). This means that the contamination incidents stated above as examples all lead to the same scenario.

This assumption also means that both the inhalation dose from the passing radioactive cloud and the subsequent external dose (beta submersion) must be considered to be no longer avoidable. Only exposure from the remaining contamination can be avoided or reduced as a result of additional measures.

Qualitative considerations show that an area requiring measures to defend against immediate hazards due to contamination as a result of such a scenario is limited in terms of size. However, it cannot be ruled out that the general public in a wider circle may need to be issued with warnings to minimise the risk of unintentional incorporation of alpha or beta emitting radionuclides.

The existence of such contamination cannot be determined without further indications such as random measurements, information and indications, the occurrence of corresponding health issues and their appropriate interpretation. In the case of assumed alpha or beta emitting radionuclides, the measurements may come about if there are any reasons for suspecting such.

Therefore it cannot be ruled out that some time may pass between the occurrence and detection of a release. This in turn means that measures to reduce contamination may not be performed until a later time.

3 Radiation protection principles relevant to the question

3.1 Reference level

In an emergency exposure situation (ICRP 2009a) or existing exposure situation (ICRP 2009b), reference level means the dose level above which it is judged inappropriate to allow exposures to occur, and below which optimisation of protection should continue to be implemented (Euratom 2014). Depending on the incident type, planning should involve a reference level for the general public[9] within a range of 20 mSv to 100 mSv residual effective dose per year or below if feasible in the given scenario. The upper threshold of 100 mSv during the first year is justified from a radiological perspective as this dose is well below the threshold for deterministic effects and because statistically significant stochastic effects among a population exposed to such an extent are only possible above this dose level (ICRP 2007). Lower reference levels lead to lower risks for stochastic effects.

The reference level should be set for a representative person (poss. also several representative persons if special protective measures are deemed necessary for them). According to ICRP 101 (ICRP 2006), a representative person is an individual who is representative of the most highly exposed individuals in the population. In the past this group of people was referred to as critical group. Based on the explanations in (ICRP 2007), the ICRP has not made any changes to the concept; it has simply refrained from using the word “critical” within this context. Chapter 6 provides further details about the representative persons under consideration here.

3.2 Intervention levels and operational intervention levels to be applied

In order to have decision criteria available that can be swiftly used to defend against immediate hazards, especially during the early phase, triggers should be set as stipulated in (ICRP 2007) and (ICRP 2009a). Triggers may, for example, be projected doses that are subsequently formulated as dose-related intervention levels. They may also include operational intervention levels such as dose rates or activity per area levels.

Here it is assumed that the intervention levels stipulated in the Radiological Principles (SSK 2014) are applied as triggers.

The effective dose is the value used by the ICRP (ICRP 2007) to evaluate compliance with the protection goals for doses up to around 100 mSv per year which are only expected to involve

[9] According to Article 53 of Directive 2013/59/Euratom (Euratom 2014), reference levels for occupational emergency exposure shall be set, in general below an effective dose of 100 mSv. In exceptional situations, in order to save life, prevent severe radiation-induced health effects, or prevent the development of catastrophic conditions, a reference level for an effective dose from external radiation of emergency workers may be set above 100 mSv, but not exceeding 500 mSv.

stochastic effects. This level cannot be applied to situations in which organ-specific thresholds for deterministic effects are expected to be reached or exceeded. At doses where deterministic effects are to be expected, the absorbed dose is the determining factor. (ICRP 2007) stipulates several thresholds for deterministic effects to be used in emergency exposure situations. Use of the above intervention level (and evacuation level described below) to trigger measures means that the reference level for the residual effective dose of 100 mSv in the first year is not exceeded and that deterministic effects are avoided, which in turn means that organ-specific absorbed doses do not need to be considered as trigger criteria for measures in this recommendation.

Levels of ground contamination in Bq m^{-2} for the various radionuclides or radionuclide mixtures are derived from the intervention level of 10 mSv effective dose in 7 days. If larger areas in the environment are contaminated to the extent of the operational intervention level, this will lead to an effective dose of 10 mSv for a person who remains outdoors permanently for a period of 7 days. Nuclide-specific operational intervention levels for ground contamination are described in Chapter 7.

In principle, every potential exposure pathway should be taken into consideration when it comes to the reference level. In the incident described in this recommendation which leads to contamination of an urban environment with alpha or beta emitting radionuclides, only certain exposure pathways will be considered. Chapter 5 includes a description of the exposure pathways that are relevant to the scenarios under consideration here.

Typical local dose rate measurements are not considered for alpha and beta emitters, meaning that the local dose rate is unsuitable as a trigger criterion for measures. Surface contamination is practically the only quantity that can be measured directly with contamination monitors, thus making ground contamination practically the only suitable quantity for measurement with contamination monitors (see Chapter 11 for details of measuring strategies). In the scenario under consideration, airborne activity and, as a result, the inhalation pathway is possible due to resuspension and also the reason why this pathway is taken into consideration as well. However, operational intervention levels are not provided for the airborne activity concentration since factors such as wind speed lead to greater variability than with ground contamination. In the case at hand, the results of measurements of airborne activity concentration are only to be seen as supplementary information.

3.3 Protection strategies

The aim of the protection strategy is to limit exposure to the public and emergency workers in order to avoid deterministic radiation effects and minimize the risk of stochastic radiation effects. The operational intervention levels provide a basis for ensuring compliance with the intervention levels set out below as well as the reference level for the residual effective dose of 100 mSv (SSK 2014) in the first year that applies to such emergency situations. The aspects of the protection strategy set out below meet the requirements of Article 73 of Directive 2013/59/Euratom (Euratom 2014).

The protection strategy for the scenario under consideration includes the following aspects:

a) As soon as there are any indications of contamination, a suspected area must be defined in which measures may be required to defend against immediate hazards. According to (IAEA 2006), such an area should initially involve a radius of around 400 m from the source. As a precaution, this area should be closed off to people who are not emergency workers. Unless particular circumstances such as police investigations require otherwise, the general population is permitted to leave the area defined as being a suspected area without any limitations. Initial demarcation of a suspected area may be performed using corresponding forecasting tools such as the LASAIR programme (Walter and Heinrich 2011).

b) It also cannot be ruled out that contaminations may occur in a wider area which may lead to substantial doses via the ingestion pathway. An example of this would be the contamination of open foodstuffs due to a radioactive cloud passing by. Given this potential scenario, a precautionary warning should be issued to the general public to tell them not to consume such foodstuffs, to avoid potentially contaminated objects and to prohibit children from playing outdoors until further notice. Distances such as those for the suspected area cannot be calculated without knowing which radionuclides are involved and the level of contamination present. Based on the proposal in (IAEA 2013), the German Commission on Radiological Protection recommends initially issuing such a precautionary warning up to a distance of 8 km within a sector of 45 degrees in the cloud's drift direction (see Annex A-5.5 for further details). The IAEA recommendation is based on a major nuclear power plant accident involving significant releases and a different nuclide spectrum. This means that the area for which warnings must be issued needs to be larger.

c) Measurements are then used to demarcate the affected area (see Chapter 11). Affected areas are defined areas in which measures to defend against immediate hazards are required for radiological reasons. The definition also includes areas in which further protective measures may be taken to reduce exposure. An affected area defined this way may be greater than the initially assumed suspected area. The operational intervention levels in this report serve as a criterion for cordoning off a limited area in which measures to defend against immediate hazards are required.

   Once measurements are available, it is possible to more accurately define the areas in which the general public should be issued with a precautionary warning against unintentional ingestion as described in b). Annex A-5 describes the options available to demarcate such areas.

d) The measures to defend against immediate hazards include the following:

   - Instruct the public to seek shelter (remain indoors), close doors and windows, and turn off any ventilation or air-conditioning systems
   - Immediate evacuation if the projected effective dose exceeds 100 mSv in 7 days without any protective measures (also to be estimated using the ten-fold level of the operational intervention level for ground contamination)
   - Limited stays through to evacuation if there is a risk of the effective dose exceeding 100 mSv over a period of 7 days when unprotected. As "sheltering" can only be enforced for around 2 days, evacuation should also be considered if the above dose criterion is not expected to be reached despite natural processes or shielding or fixation measures
   - Cordoning off an area (access control) and, after evacuating the restricted area, offering to perform contamination checks and possibly even decontamination of the public.

e) The measures are to be supplemented with conduct recommendations as part of providing the general public with regular information and warnings (e. g. limiting time spent outside of closed buildings to an absolute minimum, poss. wearing a face mask, taking off clothing and shoes worn outside before entering the place of residence, washing exposed body parts while outdoors).

f) Decontamination work should commence as soon as possible after defining an affected area. The sooner work commences, the greater the impact of decontamination. However, this should take place in a methodical manner based on order of priority and the level of contamination. Factors such as population density and traffic volume should also be taken into consideration. In order to reduce exposure due to resuspended radionuclides, contaminated areas – particularly after dry deposition and prolonged dry periods of weather – may be sprayed with water or other liquids to achieve better fixation of the contamination (Koch et al. 2012, Koch et al. 2013).

Other measures relate to the setting up of emergency units (SSK 2007b, AK V 2014) in which the population is offered contamination checks and medical consultations, while decontamination points are set up for emergency workers, their vehicles and their equipment.

3.4 Transition from an emergency exposure situation to an existing exposure situation

In particular, the decontamination measures of the affected area aim to facilitate the transition from an emergency exposure situation to an existing exposure situation as soon as possible. Initially, this means that the initial uncertainty in terms of the radiological situation is now low. It also means that affected measures such as sheltering, evacuation etc. can be revoked and the general public can go about their business as usual within the affected area or perhaps with certain limitations imposed or limits on periods of stay. This in effect means that the risk of health damage has already dropped significantly.

The target value should be a reference level set as the residual effective dose per year. This level needs to be based on the prevailing circumstances and agreed on with people affected by the measures (stakeholders). Irrespective of the fact that it should be below the level characterised by the intervention level for “sheltering” (10 mSv in 7 days), in the scenario under discussion here it should be within the upper range of the interval of 1 mSv to 20 mSv residual effective dose per year. As an existing exposure situation is also subject to measures performed on the basis of the ALARA principle, the reference level needs to be adjusted to the contamination situation from time to time.

The following figure shows an example of a flow chart for making decisions on withdrawing a measure. The measure, in this case the precautionary order to evacuate the affected area due to lack of clarity regarding the radiological situation, may also be withdrawn at the same time as implementing other optimisation measures if the reference level for returning agreed on with stakeholders can be attained.

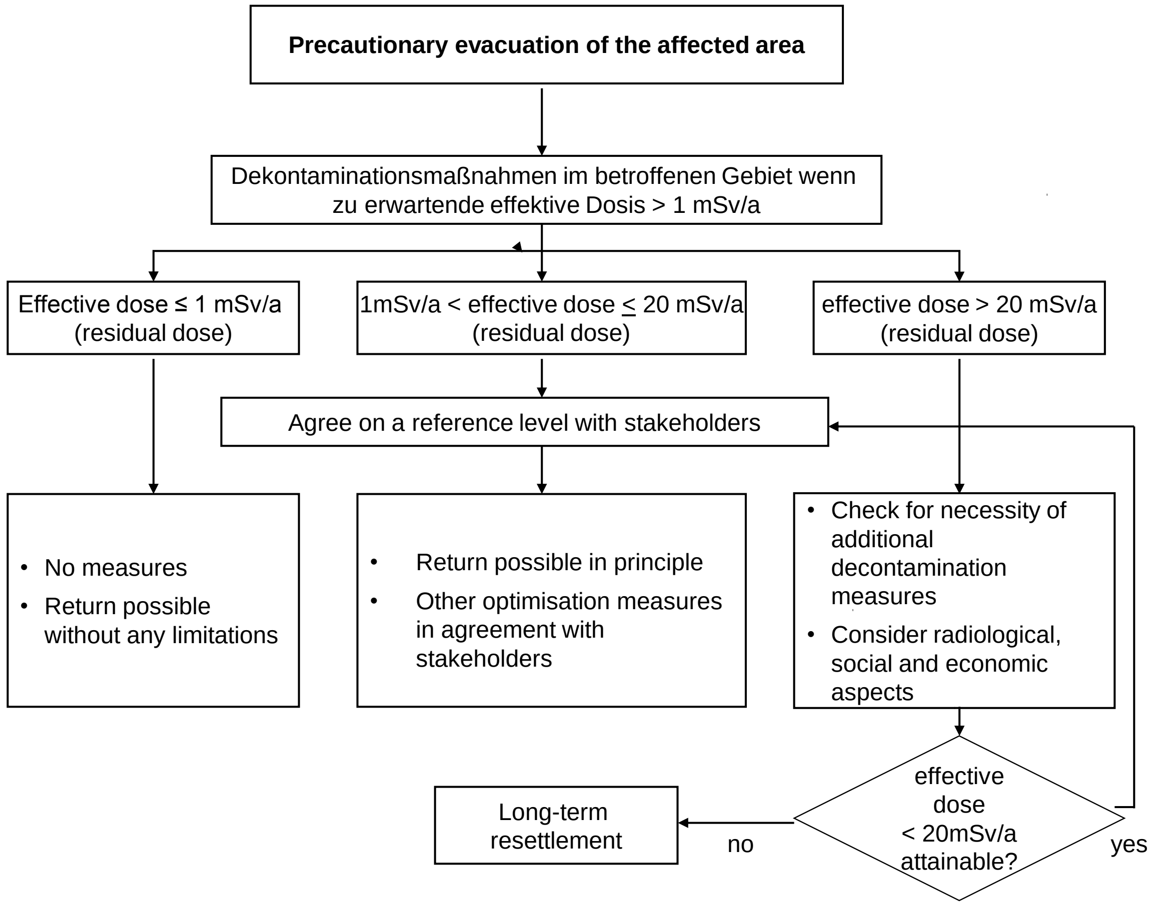

Fig. 1: Example flow chart for deriving reference levels, in this case involving a return level. The 20 mSv per year level for the effective dose set out in the flow chart should not be considered a rule-based stipulation (e. g. in SSK 2014).

4 Radionuclides to be considered

This recommendation involves a selection of the multitude of existing alpha or beta emitting radionuclides in order to limit the selection to:

- radionuclides that realistically occur in separate and highly concentrated form, and
- radionuclides with such a long half-life that mid- and long-term measures may be required until they decay.

The following approach was used in the selection process:

- First of all, the radionuclides described as alpha emitters in Section IV.6.1 of the measuring instructions for monitoring radioactivity (BMU 1993) or as beta emitters in Section IV.6.2 of the same document were selected.
- In order to account for how radionuclides are actually handled, an assessment was made to see which of the radionuclides selected during the two criteria described above are listed in the "Radionuclide and Radiation Protection Data Handbook" (Delacroix et al. 2002) together with physical data and information about protective measures.
- An internet search was performed to investigate which of the identified alpha and beta emitting radionuclides are applied in a technical (including fuel cycle), medical, military or research context. Any radionuclides not found during this process were disregarded.

- Gaseous radionuclides present were excluded with just a single exception as they will not lead to surface contamination due to deposition. Particularly with Rn-222, which is in the Ra-226 decay chain, the decay products present up until release and, to some extent, the daughter nuclides newly formed during the integration period were included in the radiation exposure calculation. Tritium (H-3) was also left out of the radionuclide selection as – when in its predominant chemical bond types - it behaves differently in the environment to the radionuclides in particle form under consideration. Tritium is also only slightly radiotoxic due to its low average decay energy (5.6 keV) when compared with other beta emitters.
- Radionuclides with a half-life of less than 1 day will not be taken into consideration as they are irrelevant when it comes to measures needed in the mid- to long-term.

After calculating the intervention levels using the specific activity of the pure radionuclide, the assessment looked into the respective radionuclide mass needed to exceed the intervention level for one of the exposure pathways under consideration. The masses needed with extremely long-lived radionuclides, may be so large that – in realistic scenarios – they can be disregarded as sources of contamination to be considered here as the mass can either no longer be distributed as contamination, or it would simply not be possible to procure such a large mass of the radionuclide. This consideration led to the radionuclides Cl-36, Zr-93, Tc-99, I-129, La-138, Nd-144, Th-230, U-233, U-236, Np-237, Pu-242 and Pu-244 being excluded. Although the above argumentation also applies to U-234, U-235 and U-238, these radionuclides have been retained in the selection because they are present in large quantities as uranium in its natural isotopic composition (U-nat[10]) or in enriched (U-5%[11]) or depleted form (U-dep[12]) and are therefore transported on a regular basis. The availability of radionuclides was not given any further consideration.

These considerations led to the radionuclides set out in Table 1, divided up into alpha emitters and beta emitters for which operational intervention levels are to be calculated.

The radionuclides marked with # in Table 1 form radioactive daughter nuclides during decay which need to be taken into account when estimating exposure. The mathematical methods are described in the Annex (in particular Annex A-1). For the purpose of the exposure scenarios under consideration here, it is assumed that the daughter nuclides contribute significantly to exposure if due to their half-life the maximum of total activity can be observed within a period of 10 years. If the maximum of total activity occurs after a period of 10 years, the radionuclide mixture is assumed to have an age of 10 years. For gaseous daughter nuclides with a half-life of more than 1 minute (Rn-222), it is assumed they were kept in a sealed container up until their release. Their short-lived daughter nuclides are then also present and when bound to aerosol contribute to exposure in the event of a release. In particular with the decay series of Ra-226, it is assumed that Rn-222 only partially emanates (50%) after a release. This proportion of the noble gas is carried away in the air from the point of emanation and is therefore no longer able

[10] Natural uranium (U-nat) is chemically separated uranium in its natural isotopic composition. One becquerel of natural uranium is equivalent to 0.489 alpha decays per second of U-238, 0.489 alpha decays per second of U-234 and 0.022 alpha decays per second of U-235. This corresponds to mass proportions of 99.275% for U-238, 0.72% for U-235 and 0.005% for U-234. U-238 is in radioactive equilibrium with its daughter nuclides Th-234 and Pa-234m after around 100 days. U-235 reaches radioactive equilibrium with its daughter Th-231 some 10 days earlier. From a dosimetric perspective, the radionuclides involved in these two decay chains do not require any further consideration. The same applies to all of the daughter nuclides in the U-234 decay chain. The # symbol indicates that the respective daughter nuclides of the uranium isotope are taken into account.

[11] In U-5%, the mass proportion of U-235 in the uranium mixture is enriched to 5%. In general, enrichment leads to an increase in the proportion of isotopes with a lower mass; this therefore increases the specific activity (Bq/kg) largely determined by U-234.

[12] Depleted uranium (U-dep or DU) means an increase in the proportion of U-238 and a decrease in the proportion of isotopes with a lower mass number. The specific activity is lower than that of U-nat.

to contribute to the dose. The remainder – together with the short-lived daughter nuclides of Rn-222 – contributes to the dose along with the longer-lived radionuclides Pb-210, Bi-210 and Po-210. Other than the previously mentioned radionuclides, only Pb-214 and Bi-214 are relevant to the dose, although this also depends on the exposure pathway.

In some cases the daughter nuclides also emit gamma radiation, which can be detected using known measurement techniques. This could justify the exclusion of these radionuclide chains from further considerations. However, they have been retained in the selection because the alpha and beta radiation may contribute substantially to exposure.

Table 1: Considered radionuclides and decay series (radionuclides marked with # are parent-daughter radionuclide mixtures that may deviate from the secular equilibrium; see Annex A-1)

Radionuclide	Considered daughter nuclides	Gamma-detectable
Beta emitters		
P-32		
P-33		
S-35		
Ca-45		
Ni-63		
Sr-89		
Sr-90#	Y-90	
Y-90		
Pr-143		
Pm-147		
Er-169		
Tm-170		
Tl-204		
Bi-210		
Alpha emitters		
Po-210		
Ra-223#	Rn-219, Po-215, Pb-211, Bi-211, Po-211, Tl-207	Yes
Ra-226#	Rn-222, Po-218, At-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210	Yes
Ac-225#	Fr-221, At-217, Bi-213, Po-213, Tl-209, Pb-209	Yes
Ac-227#	Th-227, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Po-211, Tl-207 The parent nuclide Ac-227 is a beta emitter and, with a low emission probability (< 2%), an alpha emitter (daughter Fr-223). Ac-227 is assigned to the alpha emitters because numerous daughter nuclides in the radioactive equilibrium are high-energy alpha emitters.	Yes
Th-227#	Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Po-211, Tl-207	Yes
Th-228#	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl 208	Yes
Th-229#	Ac-225, Fr-221, At-217, Bi-213, Po-213, Tl-209, Pb 209	Yes
U-234 1)		
U-235#	Th-231	Yes
U-238#	Th-234, Pa-234m	Yes
Pu-238		
Pu-239		
Pu-240		
Am-241		Yes
Cm-242		

Radionuclide	Considered daughter nuclides	Gamma-detectable
Cm-244		
Cf-252		

1) Uranium isotopes (U-234, U-235# and U-238#) as components of natural (U-nat), enriched (U-5%) or depleted uranium (U-dep). The # symbol used next to the uranium mixture designation (e. g. U-nat#) indicates that daughter nuclides have been included in the calculation.

5 Exposure pathways

According to ICRP 103 (ICRP 2007) and ICRP 109 (ICRP 2009a), all potential exposure pathways are to be considered when estimating exposure situations and assessed on the basis of their relevance to the given exposure situation.

With alpha emitting radionuclides, the exposure pathway involving external radiation of contaminated surfaces can be more or less disregarded due to the very low range of alpha radiation in matter, e. g. air.

Aside from potential ingestion, this makes exposure from resuspension and subsequent inhalation a key exposure pathway. In addition to that, the dose coefficients for inhalation of alpha emitting radionuclides are generally much higher than those for beta/gamma emitters. By contrast, external beta radiation significantly contributes to the dose with high-energy beta emitters as airborne beta particles can have a range of several metres and lead to exposure of radiation-sensitive parts of the skin[13]. In this case, both inhalation and external radiation are to be considered relevant exposure pathways, and the nuclide properties and airborne activity concentration produced by resuspension determine which of the two pathways represents the main contribution to the effective dose of a person within a contaminated area.

In the event of an alpha or beta contamination in an urban area, the following exposure pathways may be of relevance in the early phase after an accident has occurred:

- Inhalation of resuspended radioactive material

  In principle, this pathway should be considered both for alpha and beta contaminations. With this exposure pathway, adult exposure is the decisive factor due to the higher respiration rate.

- External radiation of contaminated ground

  With beta emitting contaminations, the skin dose is the decisive factor. Exposure due to beta radiation is influenced, e. g. by shielding, by means of clothing and by using the surface roughness (which is almost always available) to take cover rather than remaining in a flat area. Children may be subject to an increase in dose on account of the fact that their bodies are smaller than those of adults who, for the purpose of this recommendation, are described as representative persons based on ICRP 101 (ICRP 2006). The influence of body size will be discussed later on in this recommendation. The other effects (ground roughness, shielding by means of clothing) are not taken into consideration here as they tend to lead to a reduction in dose.

- Unintentional ingestion

  This exposure pathway was already discussed in the protection strategy (Section 3.3). The link between ground/object contamination and ingestion of contamination can be described

13 Epidermal basal cells

using an activity transfer factor, most simply by a proportionality factor. There is an extremely large number of conceivable descriptions for such a transfer whose parameters are, however, extremely uncertain (e. g. area of ground contamination being transferred to the hand, frequency of corresponding contact, efficiency of contamination transfer, path of activity transfer from the hand to intermediate items (other body parts, face) and from there to the mouth, their frequency and efficiency of transfer). The use of more or less plausible numerical values shows that the total transfer from ground contamination to ingestion can exhibit major variability, but the assumption of potential yet unfavourable conditions may lead to high ingestion doses.

As already described in Section 3.3, this exposure pathway should be excluded as far as possible by issuing specific warnings to the general public (and emergency workers).

– Dose resulting from contamination of the skin

  Members of the general public who have spent time in a contaminated area and emergency workers in said area may contaminate their clothing or skin due to coming into contact with contaminated surfaces, materials, objects and people.

– Direct inhalation of radionuclides and external radiation from a cloud passing during the release phase

  This exposure pathway was disregarded during the discussion on the scenarios to be considered (see also Chapter 2).

– Ingestion of contaminated foodstuffs

  This pathway can also be disregarded in the early phase after contamination because there is hardly any production of foodstuffs taking place in an urban area and since this exposure pathway can be prevented by issuing a precautionary warning against consuming potentially contaminated foodstuffs. It can be assumed that such a warning will be heeded and thus achieve its full effect.

  In more remote areas, increased contamination of plants and ground may occur that are used to produce foodstuffs and feedingstuffs. Offering contaminated foodstuffs and feedingstuffs for sale on the market is governed by the Precautionary Radiation Protection Act (StrVG 1986) and European regulations (Euratom 1989). The latter stipulate maximum levels for each specific activity in the given products which, if exceeded, are prohibited from being offered on the market. Compliance with bans is monitored by the authorities responsible for the inspection of foodstuffs. This helps to ensure that exposure is kept to a minimum via this exposure pathway. Depending on the circumstances, lower maximum levels can also be defined.

6 Representative persons

The scenario under consideration assumes that a contamination involving alpha and beta emitting radionuclides has already taken place and does not involve a discussion on how such a contamination may arise.

The dose that people would receive due to direct inhalation during a release is no longer avoidable or perhaps minimally avoidable by means of internal decontamination. Nevertheless, the affected persons need to be accounted for in a protection strategy e. g. by including measures to identify people and their medical treatment during the planning process.

Contamination levels are derived on the basis of dose estimates for adults.

Adults should be considered as representative persons for the inhalation exposure pathway (due to resuspended radionuclides) as they have a higher respiration rate than children. While taking account of the contributions of daughter nuclides (except for Y-90), in the radionuclide selection under consideration the higher rate of breathing among adults compensates for any higher dose coefficients that apply to children.

With the “external radiation from the ground” exposure pathway, small children aged approximately between 1 and 5 may receive higher doses than adults due to them being closer to the ground or due to playing outdoors. A rough estimate of the influence of body size can be made on the basis of figure 5.4 of the SSK publication Volume 43 (SSK 2004) where the local dose rate is divided by the activity per area prior to a contaminated area as a function of the maximum beta energy for various distances. By assuming, for example, a distance from the infinitely extended contaminated area of 20 cm for children aged 1 to 2 and 100 cm for adults, this results in a dose rate that is twice as high for children with a maximum beta energy of around 2 MeV (Y-90!).

Only beta emitting radionuclides with high emission energies (> 1 MeV) make a significant contribution to the external dose. Within this energy range, there is a 2 to 3-fold difference in dose between adults and children (estimated on the basis of body size and distance from the ground). As it can be assumed that small children, particularly in urban environments, spend more time indoors than adults, and other factors such as shielding by wearing clothing and ground roughness are not taken into account, it can in turn be assumed that the intervention level for adults also covers children.

7 Operational intervention levels (OILs) for measures during the early phase

7.1 “Determining the affected area” and “sheltering” measures

Table 2 (beta emitters) and Table 3 (alpha emitters) provide the results of calculations to determine the operational intervention levels in Bq m^{-2} on the basis of ground contamination, which would lead to an area being cordoned off and trigger the “sheltering” measure. The calculation process is described in the annexes. The final columns of each table show which exposure pathway (ground radiation, inhalation of resuspended radionuclides) leads to the lowest operational intervention levels.

As already described in Chapter 4, the intervention levels for parent-daughter radionuclide mixtures refer to the total of the individual activities of parent and daughters at the time of their maximum activity or after 10 years (see also Annex A-1).

Annex A-5 provides an exposure estimate for small children due to ingestion of soil constituents as an example of unintentional ingestion. As already described, this exposure pathway can and should be effectively halted by issuing a warning to the general public telling them not to let children play outdoors until further notice.

Table 2: Operational intervention levels for ground contamination in Bq m^{-2} from beta emitters, which lead to the effective dose reaching the intervention level of 10 mSv within an integration period of 7 days (most restrictive level for the exposure pathways inhalation after resuspension and external radiation due to radionuclides deposited on the ground)

Radionuclide	**Half-life*)**	**Operational intervention level of ground contamination in Bq m^{-2}**	**Dominant exposure pathway**
P-32	14.3 d	2.3E+08	B
P-33	25.4 d	9.0E+10	R
S-35	87.4 d	6.8E+10	R
Ca-45	163.0 d	3.5E+10	R
Ni-63	96.0 a	9.8E+10	R
Sr-89	50.5 d	2.5E+08	B
Sr-90#	29.1 a	3.0E+08	B
Y-90	64.0 h	3.3E+08	B
Pr-143	13.6 d	9.5E+08	B
Pm-147	2.6 a	2.6E+10	R
Er-169	9.3 d	1.5E+11	R
Tm-170	128.6 d	6.4E+08	B
Tl-204	3.8 a	1.5E+09	B
Bi-210	5.0 d	7.4E+08	B
Lowest operational intervention level		2.3E+08	B
Intervention level for beta contamination		1.0E+08	---

*) Half-life of the parent nuclide for radionuclides marked with #
R = Resuspension
B = Ground radiation

All of the operational intervention levels for ground contamination are well above the 1,000 Bq cm^{-2} (1.0E+07 Bq m^{-2}) level for beta emitters proposed by the IAEA. If the beta emitting radionuclide or contributing beta emitting radionuclides have not yet been identified, 1.0E+08 Bq m^{-2} should be used as a basis for decisions on initial measures to be taken in the event of beta contaminations.

Here it can be seen that contaminations of large outdoor surfaces due to corresponding incidents are only expected to reach the operational intervention levels provided here under extreme conditions.

Table 3: Operational intervention levels for ground contamination in Bq m^{-2} from alpa emitters, which lead to the effective dose reaching the intervention level of 10 mSv within an integration period of 7 days (most restrictive level for the exposure pathways inhalation after resuspension and external radiation due to radionuclides deposited on the ground)

Radionuclide	Half-life*)	Operational intervention level of ground contamination in Bq m^{-2}	Dominant exposure pathway
Po-210	138.4 d	3.0E+07	R
Ra-223#	11.4 d	3.3E+07	R
Ra-226#	1,600 a	4.1E+07	R
Ac-225#	10.0 d	5.1E+07	R
Ac-227#	21.8 a	9.0E+05	R
Th-227#	18.7 d	2.2E+07	R
Th-228#	1.9 a	1.2E+07	R
Th-229#	7,340 a	2.5E+06	R
U-nat#		2.4E+07	R
U-5%#		1.6E+07	R
U-dep#		3.0E+07	R
Pu-238	87.7 a	1.2E+06	R
Pu-239/Pu-240	24,065 a/ 6,537 a	1.1E+06	R
Cm-242	162.8 d	2.2E+07	R
Cm-244	18.1 a	2.2E+06	R
Cf-252	2.6 a	6.4E+06	R
Lowest operational intervention level		9.0E+05	R
Intervention level for alpha contamination		1.0E+06	---

*) Half-life of the parent nuclide for radionuclides marked with #
R = Resuspension

Apart from one exception (Ac-227# with 9.0E+05 Bq m^{-2}), all of the operational intervention levels for ground contamination involving alpha emitting radionuclides are above the 100 Bq cm^{-2} (1.0E+06 Bq m^{-2}) level for alpha emitters proposed by the IAEA. If the alpha emitting radionuclide or contributing alpha emitting radionuclides have not yet been identified, 1.0E+06 Bq m^{-2} should be used as a basis for decisions on initial measures to be taken in the event of alpha contaminations.

The intervention levels for beta contamination in Table 2 and alpha contamination in Table 3 have been defined as lower thresholds for the respective nuclide-specific operational intervention levels of activity per area of the alpha emitter and beta emitter nuclide groups. The operational intervention levels are based on dose calculations involving the total dose due to decay of a radionuclide or its decay series, respectively. This means that the intervention level for alpha contamination also applies to any beta emitters that may occur within the decay series.

Initial indicative measurements only show whether alpha and/or beta radiation is present. If both radiation types are simultaneously detected, it is not possible to decide whether this is radiation from several independent radionuclides such as Am-241 or Sr-90, or from a decay series such as that of U-238 without first identifying the nuclides. In this case the more restrictive alpha radiation intervention level of 1.0E+06 Bq m^{-2} should be used as a basis for decisions on initial measures.

If, at a later time, the nuclide composition of the radionuclide mixture is known and there are indications that the contamination is a mixture of the individual or parent nuclides provided in Tables 2 and 3, compliance with the operational intervention level can be verified using the following molecular formula:

$$\sum_r \frac{B_r}{ARW_r} \leq 1 ,$$

B_r is the measured contamination level for radionuclide *r*,
ARW_r is the operational intervention level for radionuclide *r*.

This molecular formula can only be applied if the nuclide composition of the radionuclide mixture is already known.

Here it can also be seen that contaminations of large outdoor surfaces due to corresponding incidents are only expected to reach the operational intervention levels provided here under extreme conditions.

Chapter 11 contains a discussion on measuring strategies for determining when intervention levels are exceeded.

7.2 Intervention levels for personal decontamination

People affected by an incident involving a radioactive release and emergency workers who spend time in or on the edge of an affected area as a result of performing rescue, demarcation, measuring or decontamination work may contaminate their clothing or skin by coming into contact with contaminated surfaces, materials, objects and people. Alpha and beta particles can lead to exposure of the skin if they are deposited on the surface of the body and remain there for a prolonged period.

The risk of exposure due to contamination can be reduced by suitable protective measures (see Chapter 10). Although the majority of external contamination can be eliminated by taking clothes off after performing such work, it is still possible for some contamination to remain on uncovered areas of the skin. The local dose resulting from direct contamination of the skin is therefore considered to be a potential exposure pathway. This includes, in particular, areas of the skin that are usually uncovered such as the face, and areas of skin revealed as a result of mechanical damage to gloves or protective clothing.

In the event of contamination of the skin or clothing, it cannot be ruled out that part of the activity ends up in the digestive system due to touching the contaminated area of skin and then touching the mouth, which in turn leads to an ingestion dose.

As already described in the protection strategies (Section 3.3), the general public and emergency workers should be provided with the option to have contamination checks and controlled decontamination in emergency units or other corresponding facilities.

Two situations should be considered in connection with this:

- An emergency exposure situation as defined by the ICRP (ICRP 2006, ICRP 2009a) is present after becoming aware of a contamination at a level that requires the stipulation of an affected area and protective measures for the general population. This is characterised by the fact that there is no detailed information available for the situation at hand and also due to the fact that potential doses may be high. In the scenarios under consideration, uncertainty is the result of a lack of precise knowledge of the level of contamination and extent of the affected area. Uncertainty, in particular, is also due to not knowing which kind of radionuclides are involved. Early measures to limit and reduce damage, e. g. by fixation of contamination, as well as contamination checks and personal decontamination take place during this emergency exposure situation.
- The transition to an existing exposure situation comes after clarifying the situation, performing protective measures for the general public, and achieving initial success in fixing the contamination, which is supported by natural processes such as a decrease in the resuspension rate over time. In this situation, additional measures are carried out, in particular, to reduce the dose, with such measures being performed according to the ALARA principle. To this end, every kind of emergency worker is deployed, e. g. to cordon off the affected area, perform clean-up work, and clean the contaminated area.

7.2.1 Dose-related intervention levels for personal decontamination

Decision criteria in the form of measurements of activity per area of the skin and clothing are required to trigger personal decontamination. In order to calculate these operational intervention levels, dose-related intervention levels for the various groups of people (general public, emergency workers) first need to be stipulated.

The German Radiation Protection Ordinance (StrlSchV 2001) in accordance with the recommendations issued by the ICRP (ICRP 1999, ICRP 2006) provides a special limit for the local organ dose equivalent of the skin as the effective dose limit does not provide sufficient protection against local tissue reactions in the event of inhomogeneous radiation from non-penetrating radiation. Pursuant to Section 46(2) of the German Radiation Protection Ordinance (StrlSchV), the limit of the organ dose equivalent for the skin shall be 50 mSv per year at a tissue depth of 0.07 mm and averaged over 1 cm^2 for members of the public, while Section 55(2) stipulates that the limit of the organ dose equivalent shall be 500 mSv per year for occupationally exposed individuals. The parts of the German Radiation Protection Ordinance quoted here refer to planned exposure situations, and these definitions are also included in Directive 2013/59/Euratom (Euratom 2014).

According to (ICRP 2007) and (Euratom 2014), the equivalent dose for the skin of emergency workers[14] should be below 500 mSv per incident as per the limit for occupationally exposed individuals, averaged over any 1 cm^2 of skin, irrespective of the exposed area.

The above documents (ICRP 2007, Euratom 2014) do not provide a value as a skin dose reference level for the general public in an emergency exposure situation. (IAEA 2005) proposes urgent personal decontamination in an emergency situation if it can help prevent a skin dose of 100 mSv from otherwise occurring within the space of a few days. This level should take account of the risk of spreading contamination, inadvertent incorporation, and possible detection under emergency conditions, while also ensuring an adequate gap from deterministic skin damage.

[14] Emergency worker means any person having a defined role as a worker in an emergency and who might be exposed while taking action in response to the emergency (definition 31 in (Euratom 2014)).

Following the transition to an existing exposure situation, in keeping with radiation protection provisions, the ICRP (ICRP 2007) stipulates that the organ equivalent dose for the skin should be limited, as is the case in a planned exposure situation (see above).

The local skin dose calculations described below and their resulting operational intervention levels show that there are three different groups of radionuclides: Beta emitters, alpha emitters and their accompanying decay chains with alpha energies of < 6.5 MeV (cf. Annex A-4.1) and alpha emitters with alpha energies of > 6.5 MeV or decay chains containing alpha emitting radionuclides with alpha energies of > 6.5 MeV.

It can be assumed that regular contamination checks and personal decontaminations of the general public in emergency units are generally no longer needed due to the much lower contamination level present in the environment at that time. Corresponding measures, i.e. contamination checks and, if necessary, decontamination, remain necessary for emergency workers who perform duties such as clean-up and decontamination work, detection and decontamination of hot spots, at least until they have completed these tasks. According to the points raised above, a dose-related intervention level of 50 mSv per year for the local organ dose equivalent of the skin shall apply to this group of people.

Personal decontamination is a measure requiring little effort – careful washing of the affected area of skin, poss. showering (SSK 2006, SSK 2007b) – and has no negative impact whatsoever on the person involved. For this reason, the German Commission on Radiological Protection recommends a uniform dose-related intervention level of 50 mSv, despite the biological effect of low skin doses being deemed negligible (Preston et al. 2007). A low intervention level is therefore based on the premise that a measure does more good than harm. A uniform intervention level also helps to simplify things as the possible combinations of exposure situations (2), groups of people (2) and nuclide groups (3) would require the stipulation of multiple operational intervention levels for triggering skin decontamination. The dose related intervention level of 50 mSv therefore only serves to trigger personal decontamination and should not be considered a general limit.

This dose-related intervention level for personal decontamination is therefore much lower for emergency workers than the 500 mSv limit, but still leaves scope for additional emergency deployments after performing personal decontamination. When subjecting emergency workers to radiation protection monitoring as prescribed in Directive 2013/59/Euratom (Euratom 2014), it must be ensured that multiple exposures do not lead to the skin dose of 500 mSv being exceeded wherever possible.

The recommended dose-related intervention level for triggering personal decontamination is still within the annual limit for the normal population in a planned exposure situation. However, this is justifiable in an emergency exposure situation. According to (ICRP 2007) and (IAEA 2005), a higher intervention level would certainly be conceivable for initiating decontamination after transporting contamination away from an affected area as this is a one-off event and the higher intervention level of 500 mSv for occupationally exposed individuals still provides enough of a margin from the occurrence of local tissue effects.

In terms of a potential ingestion dose via the skin/clothing-hand-mouth pathway, the German Commission on Radiological Protection recommends an intervention level of 1 mSv for the effective dose in all exposure situations.

7.2.2 Operational intervention levels for personal decontamination

Annex A-4 describes the calculation of the local skin dose and (nuclide-specific) operational intervention levels derived therefrom to be used as trigger criteria for personal decontamination.

This allow the skin dose intervention level stipulations to be used to derive the following trigger criteria for personal decontamination.

Table 4: Operational intervention levels of the measured activity per area on the skin and/or clothing (in Bq cm^{-2}) which, if exceeded, should trigger personal decontamination. Basis: Dose-related dose intervention level of 50 mSv for the skin dose and 1 mSv for the effective dose due to unintentional ingestion.

Exposure situation	Radionuclide group	Intervention level
Emergency exposure situation and subsequent existing exposure situation	Beta emitters other than Ac-227#	100 Bq cm^{-2}
	Alpha emitters or decay series with alpha energies of >6.5 MeV and Ac-227#	1 Bq cm^{-2}
	Alpha emitters or decay series with alpha energies of <6.5 MeV	1,000 Bq cm^{-2}

Alpha emitters or decay series with alpha energies of >6.5 MeV include the following radionuclides: Ra-223#, Ra-226#, Ac-225#, Ac-227#, Th-227#, Th-228#, Th-229#. The beta emitting radionuclide Ac-227# can be included in this group because the decay chains largely match those of various high-energy alpha emitters (see also the note in Table 1). All of the radionuclides in this group have gamma emitting daughter nuclides, but the highest skin dose contributions come from high-energy alpha emitting daughter nuclides such as Po-212, Po-213, Po-215 and At-217.

Alpha emitters or decay series with alpha energies of <6.5 MeV include the following radionuclides and radionuclide mixtures: Po-210, Pu-238, Pu-239/Pu-240, Am-241, Cm-242, Cm-244, Cf-252, U-nat#, U-5%#, U-dep#.

In spite of the model-based derivation frequently providing similar levels, the operational intervention levels for skin contamination calculated here differ greatly from the surface contamination levels set out in Annex III table 1 column 4 of the German Radiation Protection Ordinance (StrlSchV). Outside of radiation protection areas, both on and outside of the premises, the levels provided in Section 44(2) and (3) of the German Radiation Protection Ordinance (StrlSchV) apply to the surface contamination of objects and, among other things, clothing. These levels should prevent uncontrolled dissemination of contaminations from occurring in public areas as a result of practices in planned exposure situations. As well as a different dose criterion (10 µSv per year for the effective dose), they are based on other exposure scenarios with widespread contamination of objects and long exposure times. The scenarios in Annex III table 1 of the German Radiation Protection Ordinance (StrlSchV) do not take account of the skin dose due to high-energy alpha emitters.

The intervention levels calculated here only refer to emergency exposure situations and existing exposure situations. These two contamination level sets cannot be compared with one another, neither in terms of their objective, nor on the basis of their underlying exposure scenarios and model parameters.

8 Information about protective measures

The underlying scenario assumes that contamination involving alpha or beta emitting radionuclides has already taken place. This contamination can be found on the ground and on objects that were in the vicinity of the point of release or area where radioactivity was deposited by the ensuing radioactive cloud. If the release took place outside of buildings, the contamination will be highest there. In such a situation, areas and objects inside buildings may also be contaminated, be it due to open windows, doors or ventilation shafts at the time of release, or due to the spread of contamination, e. g. on contaminated shoes and clothing. However, in such cases, indoor contamination should be much lower than that found outdoors as there may well be resuspended radionuclides in the air.

In this situation there are two main objectives:

- Contaminated persons, particularly those with open wounds, must be identified, decontaminated if necessary, and, where also necessary, treated (see Chapter 12 on medical measures).
- The affected area must be demarcated and the impending future exposure reduced as per the ALARA principle.

Reduction of exposure takes place by means of eliminating the contamination (decontamination in the stricter sense) and/or by applying shielding or fixing material to the contamination, in the latter case in order to prevent resuspension from occurring. A resuspension suppression measure that has already proven highly effective in the past when the weather is dry involves spraying surfaces with water, and this measure can be performed immediately after identifying the contamination (Koch et al. 2012).

(Nisbet et al. 2009) describe the main options available to decontaminate the affected area. The majority of decontamination measures are most effective when performed shortly after contamination. Decontamination of roads and pavements generally involves hosing them down with water (fire brigade hoses) and the use of road sweepers. Decontamination of buildings (roofs, walls) may be carried out with high-pressure cleaners, with workers being required to wear a respirator. If, during contamination measures, water flows into the sewage system that is contaminated with alpha or beta emitters, this is generally considered to be safe. There may be situations in which it is difficult to use water, e. g. during freezing conditions.

If the measures described above are insufficient, then longer-term and usually very cumbersome measures are required, such as turning over cobblestones or removing surfaces.

Grassed areas can be mowed and the contaminated cuttings stored away from residential areas until a later date. The same applies to areas with contaminated snow.

In general, decontamination leads to contaminated waste[15] which needs to be treated or removed.

(Nisbet et al. 2009, datasheet no. 49) also discusses treatment using film-forming substances that can be sprayed on or applied with brushes in order to prevent resuspension and as a decontamination measure. The agents bind the radioactive substances to the surface as a removable film. Acrylic-based agents for binding residual fibres are also feasible[16]. The binding agents and the radionuclides bound to them can be subsequently removed and disposed of as radioactively contaminated waste. With the exception of the acrylic-based binding agents, these methods are only suitable for small areas and should be used if the contamination is still on the

[15] Here a distinction is made between contaminated waste and radioactive waste. The latter is the result of practices and activities subject to the provisions of the German Radiation Protection Ordinance (StrlSchV) (chapter 3, section 9) and the Atomic Energy Act. (Küppers et al. 2010) discuss legal requirements with regard to the disposal of agricultural waste contaminated with radioactivity in cases involving precautionary radiation protection measures. There is still no legislation for this, however. From the point of view of this recommendation, any waste contaminated with radioactivity resulting from decontamination work should also be included in legislation.

[16] Personal message from Kerntechnische Hilfsdienst GmbH – KHG to the SSK dated 23 April 2012

surface. They can be used in dry weather and, to some extent, on smooth surfaces. No further discussion will be offered here in terms of cost and availability.

9 Informing the general public

The general public is alerted to a release by means of media reports and personal communication. Both immediately affected members of the public and people living nearby or who are not or barely affected by the release will be concerned as to whether the contamination may be detrimental to their or their families' health. They will also ask themselves whether this has a knock-on effect for them, such as limits to freedom of movement, being able to do their job, and potential property damage. Even members of the public not affected at all by the incident will be interested in what has happened and the resulting actions. Information is provided by the media, with radio, TV and the Internet broadcasting reports at a very early stage. The command centres will have little influence over the content, correctness and appropriateness of what is disseminated by the media, which is why it is important to be aware of any special requirements of these media and to act as a reliable source of information. The guideline for the information of the public in case of nuclear accidents (SSK 2007a, available only in German), the TMT handbook (Rojas-Palma et al. 2009), the brochure "Crisis Communications for Emergency Responders" (EPA 2007) and the "Manual for First Responders" (IAEA 2006) all provide information on this topic.

It is also necessary to make sure that interested parties, particularly those directly affected by an incident, have the opportunity to address their questions to a public relations team. The requirements on this team and its spokesperson(s) are described in detail elsewhere (e. g. EPA 2007, Rojas-Palma et al. 2009). The tasks associated with public relations work are of major significance.

Members of the public directly affected by measures will have highly specific questions and will be far more likely to ask them than members of the public who are not within the area to be subject to measures. Many such questions (e. g. meaning of measured values, how to handle contaminated objects and vehicles) will be predictable and are most likely to be asked in emergency units or other similar facilities. The SSK therefore encourages the development of a communication concept in advance so that emergency and support workers in direct contact with affected members of the public are able to provide appropriate answers to such questions. A concept like this needs to be designed such that emergency and support workers can be informed and instructed at very short notice.

10 Information to protect emergency workers

In order to perform a variety of measures, emergency workers who are not usually occupationally exposed persons are required, for example, to rescue injured persons, take measurements, cordon off areas, monitor the affected area, perform decontamination work (people and instruments, areas), and treat and remove contaminated waste.

If the police and fire brigade are involved, they are subject to regulations (Police 2006, AFKzV 2012) governing their deployment in contaminated areas. However, these regulations largely focus on contaminations from gamma emitters. In such cases, external radiation can be measured easily using dose-rate measuring devices and, as a result, the danger area with a dose rate of > 25 $\mu Sv\ h^{-1}$ can be demarcated. If areas are contaminated with alpha or beta emitters without any relevant gamma radiation contribution, such demarcation is difficult to perform using a dose-rate criterion. The contamination can be measured using mobile alpha/beta sensitive contamination measuring devices. The nuclide-specific operational intervention levels in this report to trigger the “sheltering” protective measure in the event of contamination of outdoor areas are often much higher at levels above 1.0E+6 Bq m^{-2} for alpha emitters, and even higher at levels above 1.0E+8 Bq m^{-2} for beta emitters. This means that such contamination levels are at least two and generally several orders of magnitude higher than the detection sensitivity of conventional handheld contamination measuring devices for alpha and beta radiation, meaning that they are easy to detect with such measuring devices.

If areas are contaminated with alpha and beta emitting radionuclides with a low gamma radiation contribution, the dominating exposure pathways for emergency worker practices are inhalation of radionuclides following resuspension and external radiation of the skin from high-energy beta emitters. The operational intervention levels set out in Tables 2 and 3 for contamination of outdoor areas that trigger the temporary “sheltering” measure are based on the assumption that a person remains in an area with such contamination for a period of 7 days without any protection, thus receiving an effective dose of 10 mSv. A dose of 10 mSv in 7 days corresponds to an average dose rate of 60 µSv per hour. The dose from incorporated radioactive material is, to be precise, a dose commitment that accumulates over time, but is generally attributed to the incorporation time. Such an average dose rate due to external beta radiation and inhalation following resuspension would lead to an effective dose of less than 1 mSv over the course of a 10-hour deployment.

However, such exposure conditions, which are more or less constant over time, do not apply to inhalation following resuspension. The modelling for exposure due to inhalation of resuspended radionuclides described in more detail in Annex A-2, which also includes more recent experimental investigations into the level and time dependency (Koch et al. 2012, Koch et al. 2013) of resuspension due to the influence of wind in the early phases after a contamination, shows how resuspension processes are highly dependent upon time. As a result, emergency workers are mainly exposed in the first few hours after a contamination incident due to inhaling resuspended radionuclides. However, this exposure can be reduced significantly by means of easy-to-perform measures that reduce the resuspension of contaminated areas and by performing simple respiratory protection measures. However, external radiation of the skin by beta emitting radionuclides would occur over prolonged periods and only decline due to radioactive decay (half-life) and as a result of weathering or decontamination measures. This is therefore more like the situation involving an average dose rate of 60 µSv h^{-1} with contamination in line with the operational intervention levels provided here.

Emergency worker exposure can be reduced significantly if the emergency workers conduct themselves appropriately and by means of easy-to-perform protective measures:

The easiest thing to implement are measures that reduce the resuspension of contaminated surfaces. The reports by (Koch et al. 2012, Koch et al. 2013) investigate the effectiveness of simple measures to fix a contamination for a multitude of representative surfaces, e. g. in an urban area. Spraying surfaces with water or a mixture of water and glycerine (which is more effective and poses no threat to health) reduces resuspension 10 to 100 times. Early measures to fix contamination after deposition of dust on surface is recommended in order to quickly suppress resuspension due to wind. This also applies in terms of reducing resuspension from people or vehicles moving around contaminated areas, as walking or driving there causes dust to rise as a result of the induced airflow.

Conventional hygiene protection measures are recommended in order to protect workers. Such measures include wearing light contamination protection clothing to prevent contamination from being transferred to the skin, and wearing a simple, light face mask. FFP 2 respirators are typical face masks that provide good respiratory protection without impeding physical work, at least in contamination situations in which the operational interventions levels stated here are not exceeded significantly.

Emergency workers who spend time in or in the immediate vicinity of an affected area in order to perform rescue, demarcation, measuring or decontamination work may contaminate their clothing or skin as a result of coming into contact with contaminated surfaces, materials, objects and people. Alpha and beta particles can lead to exposure of the skin if they are deposited on the surface of the body and remain there for a prolonged period.

Suitable protective measures such as wearing contamination protection clothing can reduce the risk of exposure from contamination. The risk of exposure due to incorporation can also be reduced by following conduct instructions (e. g. no eating, drinking or smoking during the deployment, avoiding contact with the mouth). Due to its low range in matter, alpha radiation cannot penetrate clothing. With beta radiation, the shielding effect of clothing depends on the beta radiation's maximum energy. A 3 to 5 times reduction in beta radiation with high maximum energies of 2 MeV, as is the case with Y-90 or P-32, is achieved by wearing robust protective clothing (Jensen 1992). With low beta energies below 0.5 MeV, the reduction due to wearing protective clothing is more than a factor of 100.

The majority of external contamination can be eliminated by taking clothes off after completing a deployment. Uncovered areas of skin must be checked for residual contaminations in order to prevent local skin exposure. Intervention levels for contamination checks can be found in Section 7.2; see Annex A-4 for their calculation.

The majority of emergency workers have occupations in which they almost never come into contact with radiation from radioactive material and for which the regulations incumbent upon the fire brigade and police do not apply (e. g. street cleaners, construction workers). According to Fire Service Directive 500 (FwDV 500 - AKFzV 2012), a dose constraint[17] of 15 mSv for the effective dose applies to non-occupationally exposed members of the fire brigade deployed to protect material assets. As stipulated in guideline LF 450 "Hazards due to chemical, radioactive and biological substances" (PolizeiLF450 2006), a dose constraint of 6 mSv for the effective dose per deployment (and year) applies to police officers deployed to protect material assets. According to both of the above regulations, 100 mSv is the effective dose limit per deployment and calendar year when the police and fire brigade are deployed to defend against hazards to people and to prevent any damage escalation. An effective dose with a dose constraint of 6 mSv or 15 mSv resulting from a very rare radiological incident does not constitute a disproportionate health hazard. Exposures at this level are within the limits of average natural exposure received during a period of 3 to 7 years. Any other adult workers deployed during the early phase such as street cleaners, transport staff, people tasked with clean-up work, decontamination and repairs are not subject to any disproportionate exposure risk as a result of receiving an additional dose at this level. National and international radiation protection principles of justification and optimisation must obviously be observed under such deployment conditions. Particularly in the case of contamination involving alpha and beta emitting radionuclides without any major contribution from gamma radiation, an exposure of 6 mSv or 15 mSv for the effective dose can barely be expected as a result of the above protective measures.

When it comes to deployments, a distinction should be made between acute measures immediately after the onset of the radiological situation and longer-term measures designed to further reduce exposures resulting from the incident:

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[17] In ICRP 103, the term dose constraint is used in conjunction with planned exposure situations. Here it is still used within the context of FwDV 500 and LF 450.

Acute measures are: Rescuing people, preventing damage escalation (e. g. by housing the source), and early measures to suppress resuspension. The exposure situation is initially characterized by the fact that there are no specific details available regarding the contamination situation and radionuclides involved. In this situation, detection of exposure by emergency workers is particularly difficult as dosimeters used by the fire brigade and the police only show the dose resulting from gamma radiation. Only special institutions have dosimeters for beta radiation, and they are likely to be available only at a later stage and in small quantity. This means that the dose can only be measured indirectly and subsequently by means of analyses that include measurements of the given surface contamination that were taken by contamination monitors, swipe samples and possibly also air activity measurements and recording of deployment types, tasks and locations.

Longer-term measures include, in particular, decontamination and various clean-up duties. Although such measures should be initiated as soon as possible in order to achieve good decontamination results, it is important to first plan these measures while observing radiation protection aspects so as to protect emergency workers. Longer-term work should be performed according to “normal” radiation protection regulations. Among other things, this means that dose limits for occupationally exposed individuals and non-occupationally exposed individuals should be applied. Emergency workers will want to reassure themselves of the potential hazards they may be faced with while performing their various duties (e. g. rescuing people, performing measurements, cordoning off areas, monitoring areas, performing decontamination work or medical tasks). A lot of emergency workers have as little knowledge of radiological hazards as the general population, which is why it is important to educate emergency workers about the hazards involved (e. g. incorporation of radioactive material, dealing with contaminated persons) and, in particular, the necessary protective measures (e. g. general hygiene, wearing face masks, limited deployment times, changing work clothes after completion of deployment, ban on eating and drinking during deployment) before being deployed. It is essential that the command centre involves radiation protection experts and informs emergency workers before and during their deployment while also adequately recording their exposure as a result of their deployment.

11 Information about measurements

When unusual events such as car fires or explosions occur in the public domain, widespread contamination involving alpha or beta emitters is often only detected if there are indications that radioactive material is present, e. g. if indications of sources or shielding material are discovered or if indicative measurements are performed where the incident occurred. In such cases, these measurements are performed by the fire brigade, police and disaster control authorities of the respective federal state (Bundesland). The technical measuring devices and expertise available there are not designed to detect widespread contaminations with non-penetrating radiation. During initial deployment, members of the fire brigade and police focus on defending against the immediate hazard and limiting damage. Measurements – if any are taken at all – to exclude a radioactive material release are generally limited to measuring the local gamma dose rate. For this reason, emergency worker training and instruction should in future focus more on the potential presence of contaminations that cannot be detected using conventional dose-rate measuring devices. A series of the alpha emitting radionuclides considered here can be detected by the local dose rate emitted by the daughter nuclides and possibly identified by subsequent gamma spectrometry. Additional checks should therefore also always be made during gamma radiation detection to see whether the alpha or beta emitters in this recommendation are present in relevant activities. In order to achieve this, suitable contamination measuring devices must be available to measure alpha radiation.

The following description outlines the objectives of performing measurements and the options currently available in order to achieve these objectives.

The first objective of measurements is to exclude radiation contamination in unusual situations. As well as the usual local gamma dose-rate measurements, indicative measurements can be taken using mobile alpha/beta-sensitive contamination measuring devices with gas-filled detectors or thin-layer plastic scintillators which the CBRN[18] reconnaissance vehicle (CBRN ErKW), police and fire brigade radiation detection squads, state measurement laboratories and other competent state authorities are supplied with. More modern devices can set the discriminator threshold for alpha or beta radiation such that it is possible to distinguish between the two types of radiation. Commercial devices can detect contaminations of around one Becquerel per cm^2 if measuring times are short. As this initially involves qualitative contamination detection, there are only low requirements with regard to measurements. The main influencing factors, i.e. the local blank count rate above what is certain to be an uncontaminated surface as well as a sufficiently low distance of about 1 cm between the detector and the surface to be measured, must be observed when taking measurements.

If a contamination is detected, the next step, i.e. the second objective of measurements, is to determine the extent of the affected area. To this end, a surface contamination level should be defined using the operational intervention levels provided in this recommendation that then serves as a threshold for deciding between "measure required" and "measure not required" as per Section 3.3c.

As long as the radionuclide (mixture) has not been identified, the intervention levels for ground contamination with alpha and beta emitters provided in Section 7.1 can be used for initial measurements. Information provided by the manufacturer on calibration factors for gross alpha or gross beta can be used to convert impulses per second to activity per area in Bq cm^{-2} (cf. Annex A-7). If these calibration factors are not available, a calibration factor for a suitable substitute nuclide such as Am-241 can be used for alpha emitters or Cl-36 for beta emitters. The measurement results can be converted to match the actual radionuclide using the relevant calibration factor once the radionuclide present has been identified.

Initially, the choice of measurement locations can be based on dispersion calculations (e. g. LASAIR, Walter und Heinrich 2011) with a focus on demarcating areas in which measures are required. Measurement locations are sought where the intervention level is just reached and through which a solid line can be drawn around the point of release. The mobile contamination measuring devices described above are used to perform measurements. In order to be able to compare measurement results quantitatively, the measurements must be taken on level, ideally smooth and dry surfaces, and at a constant distance of around 1 cm from the surface. This measurement procedure can be improved by mounting the measuring devices on wheeled stands with a fixed distance to the ground, and by recording the GPS coordinates of the measurement locations in order to track the situation in the area.

If information about the radionuclide(s) is already available, ascertainment of the affected area during the first phase can be supported by determining the local gamma dose rate for certain radionuclides at a height of 1 m from the ground. Annex A-6 provides level estimates for the gamma dose rate to be expected in contaminated areas that apply to all of the alpha emitters with gamma emitters in their decay series under consideration here.

If a mobile swipe test measuring station is available, selective swipe tests using handheld devices can also be performed.

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[18] **C**hemical, **B**iological, **R**adiological and **N**uclear hazards

As well as these measurements, the next objective is to initiate identification of the radionuclide(s). Some of the radionuclides under discussion here decay to gamma emitting daughter nuclides, meaning that an initial attempt should be made to perform an in-situ gamma spectroscopy. If that fails to detect any radionuclides, a sample of the release must be taken from the vicinity of the release and analysed in a laboratory. The type and quantity of the sample must be coordinated in advance with the laboratory. The radiochemical sample preparation methods for alpha and beta spectrometry are time-consuming as it generally takes several days to produce a measured value. This is partially due to the fact that the available measurement methods for detecting very low activities were developed within the context of environmental monitoring. The federal states (Bundesländer) generally no longer have any devices such as methane flow meters available to quickly detect high alpha and beta activities, which is why the SSK recommends the development of swift and simple measuring methods to detect alpha or beta radiation in dust and swipe samples in the event of high activity levels, and that they be supplied to the competent state authorities. In addition, a neutron radiation measurement should be performed in situ so as to limit the number of radionuclides that may be involved[19] (IAEA 2006, Rojas-Palma et al. 2009). From a dosimetric perspective, the neutrons are of no consequence to the nuclides and exposure pathways under consideration here.

A close-meshed survey of the affected area within the identified demarcation is initially of secondary importance for initiating and performing measures to protect the general public.

In the event of releases from explosions, larger source fragments may have been deposited up to a distance of around 100 m from the point of release. In order to protect emergency workers during clean-up work and to prevent the spread of contamination, the immediate vicinity of the point of release should be searched.

A close-meshed, systematic search should be carried out using mobile contamination monitors in order to find source fragments after a release caused by an explosion. The main objective here is to quickly find places with relative maximum count rates.

Measures initiated to defend affected persons from immediate hazards must be followed by clean-up and decontamination measures within the demarcated area in order to ensure that the area can be used again in the long term. In order to release the area again, measurements must confirm that residual contamination is below the levels stipulated within the scope of optimisation considerations. This requires a check to ensure that decontamination measures in the affected area have been successful.

More time is available for such measurements than in the phase immediately after the release. The method and strategy to be used for these measurements can be carefully adapted to the situation. These measurements can be performed with contamination monitors after dividing up the affected area into a grid. Swipe samples should also be taken from smooth surfaces such as car roofs or bonnets and then quantitatively analysed. When choosing a suitable grid, care should be taken to ensure that no hot spots are overlooked which can occur when decontamination water converges or as a result of guttering overflow. Mobile ground monitoring systems with large-area counter tubes such as those available in nuclear facilities and companies that use nuclear fuel are suitable for measuring large areas.

Air sample analysis can also be used to check the activity concentration of outdoor air and to ensure that radionuclide resuspension suppression measures were successful. When mobile devices such as those available to detection squads for disaster control measurements are positioned in the affected area, aerosol can be applied to air filters that are subsequently analysed in the laboratory.

[19] There are only few radionuclides whose spontaneous fission rate is so high that they will cause measurable neutron flows, the main ones being Cf-252 and Pu-239/240.

In addition to the measurements described here that are carried out to ascertain the situation, contamination measurements can be performed on members of the public and emergency workers throughout the entire incident in order to determine the presence and level of contamination.

Only handheld alpha/beta sensitive contamination monitors are initially available to perform such measurements which have to be taken close to the body surface in order to be able to detect alpha or beta radiation. When measuring a person's contamination level, particular attention must be paid to their hands and face in order to avoid incorporations, the soles of their feet in order to avoid spreading contamination, and uncovered skin after taking off protective clothing.

These measurements can be accelerated if a transportable personal monitor that can be procured and installed in situ.

Contamination measurements for objects are not part of this recommendation.

Dose monitoring should be performed on emergency workers during activities in a contaminated area. The potential effective dose from inhalation can be indirectly estimated by measuring ground contamination or air concentration using deployment data (activities carried out, deployment locations, deployment periods). Upon suspicion of a substantial incorporation risk, excretion measurements can also be taken to determine the effective dose from incorporation. As already described in Chapter 10, the dose from the inhalation exposure pathway can be reduced by means of simple respiratory protection measures.

Direct radiation is a significant exposure pathway for contaminations involving beta emitters. The local beta dose rate should therefore be measured to ascertain the deployment dose. Local dose-rate measuring devices and personal dosimeters typically used by police and fire brigade detection squads are not suitable for this purpose as they only register gamma radiation. Local beta dose-rate measuring devices and beta sensitive electronic personal dosimeters are commercially available and some institutions have a small number of them.

The existing equipment used by disaster control workers and state measurement laboratories is not ideally suited to measuring tasks for widespread contamination involving alpha or beta emitters in public areas, meaning that it may be necessary to ask other institutions with suitable resources and expertise for assistance in performing said tasks. The following organisations could be called upon to assist with measuring tasks:

- The measuring unit of the Central Federal Support Group in Response to Serious Nuclear Threats (ZUB)
- Kerntechnische Hilfsdienst (KHG) GmbH
- Neighbouring nuclear power plants, companies that work with nuclear fuel, research centres or other establishments (e. g. TÜV), particularly if they have prior experience in operating, decommissioning and dismantling nuclear power plants and facilities.

Table 5 provides an overview of the measuring tasks.

Table 5: Overview of measuring tasks to detect contaminations from alpha and beta emitting radionuclides in urban areas

Measurement objective	Suitable measuring method	When to perform measurements	Remarks
Exclusion of radioactive contamination in unusual situations	Manual measurement with local dose-rate measuring devices and mobile alpha/beta contamination monitors	Immediately after an incident that may have led to a release	Qualitative detection as to whether alpha, beta or gamma radiation is present
Ascertainment of the extent of the affected area	Manual measurements with local dose-rate measuring devices and mobile alpha/beta contamination monitors	Immediately after a release has been detected	Select measuring locations based on dispersion calculations from the beginning
Identification of the radionuclide	Gamma in-situ spectroscopy and sampling and alpha/beta spectroscopy in the laboratory	After immediate measures to protect the population	Depending on the circumstances, the results may only be available days/weeks later
Find source fragments after a release caused by an explosion	Close-meshed screening measurements with mobile contamination monitors	Before commencing clean-up work	Find local maximums in the vicinity of the point of release
Check to ensure that decontamination measures in the affected area have been successful	Mobile contamination monitors, mobile ground monitors, swipe test samples, air filter samples	After carrying out clean-up and decontamination work	Careful planning is required to exclude any remaining hot spots
Perform contamination measurements on people	Measurements using handheld alpha/beta contamination monitors	Alongside protective measures for the general public; during clean-up and decontamination work for emergency workers	Measurements have to be performed close to the body surface; hands, feet and the face are particularly important
Dose monitoring of emergency workers	Measurement of local beta dose rate and beta components of the personal dose equivalent, excretion measurement upon suspicion of substantial incorporation	Alongside deployments, during clean-up and decontamination work	Due to the low number of available measuring devices, measurements should be performed at individual workplaces and on individual persons; excretion measurements should only be taken as and when deemed necessary

The SSK suggests preparing instructions on how to operate the various measuring devices during measuring tasks to be performed during the scenario under consideration here (see Section 11 and Annex A-7 of the scientific background).

12 Information about medical aspects

Contaminated wounds may occur if people are injured during an event involving releases of alpha or beta emitting radionuclides. People who spent time in the radioactive cloud will also have been exposed via the inhalation pathway. Estimates based on the ground contamination operational intervention levels set out above show that the related inhalation dose may be much higher than the dose from inhalation of resuspended particles. In fact, depending on the type of release, the radionuclide type and its activity, there may even be a risk of deterministic effects.

Both radioactively contaminated wounds and inner exposure from unavoidable inhalation require special medical measures.

First of all it is important to find everyone who has been affected this way and then perform special medical diagnostics, possibly to be followed by suitable treatment.

The principles of the respective diagnostics and treatment are described in (SSK 2006, Chapter 6). Detailed descriptions are also available in the TMT handbook (Rojas-Palma et al. 2009) and the NCRP Report 161 (NCRP 2010). Hormann and Fischer (2009) describe internal decontamination measures. The general rule is that these measures are to be performed soon after incorporation to ensure that they are effective.

It is uncertain whether the medical institutions administering initial treatment have the required expertise to do so. In such situations, the fire brigade and rescue command centres as well as the state environmental offices should ideally be informed of the institutions with sufficient expertise to provide advice, diagnoses and treatment during the planning stage. The REMPAN centre, the Regional Radiation Protection Centres of the Institute for Radiation Protection of the German Social Accident Insurance Institution for the Energy, Textile, Electrical and Media Products Sectors (BG ETEM), and the German Social Accident Insurance Institution for the Raw Materials and Chemical Industry (BG RCI) (an updated list is available using the webcode 12178646) could, for example, be appointed as command centres for corresponding facilities.

Annexes: Calculation models

A-1 Common aspects for deriving intervention levels

Determining radionuclide mixtures originating from radioactive decay

Many of the radionuclides under consideration here form radioactive daughter nuclides during decay. In the scenarios discussed in Chapter 2, it must be assumed that such a radionuclide is present in a mixture with its daughter nuclides rather than in pure form following recent separation.

Unless they can be excluded due to their half-life or physical behaviour, the radioactive daughter nuclides need to be taken into account when estimating exposure.

For the purpose of the exposure scenarios under consideration here, it is assumed that they contribute significantly to exposure if due to their half-life equilibrium or a maximum of total activity can be reached within an observation period of less than 10 years.

Figure A-1 is a simple example of the decay series of Sr-90 and also shows how the daughter nuclide Y-90 is formed and subsequently contributes to activity. Maximum total activity is reached after around 30 days; from that time on the parent and daughter nuclide are in secular equilibrium.

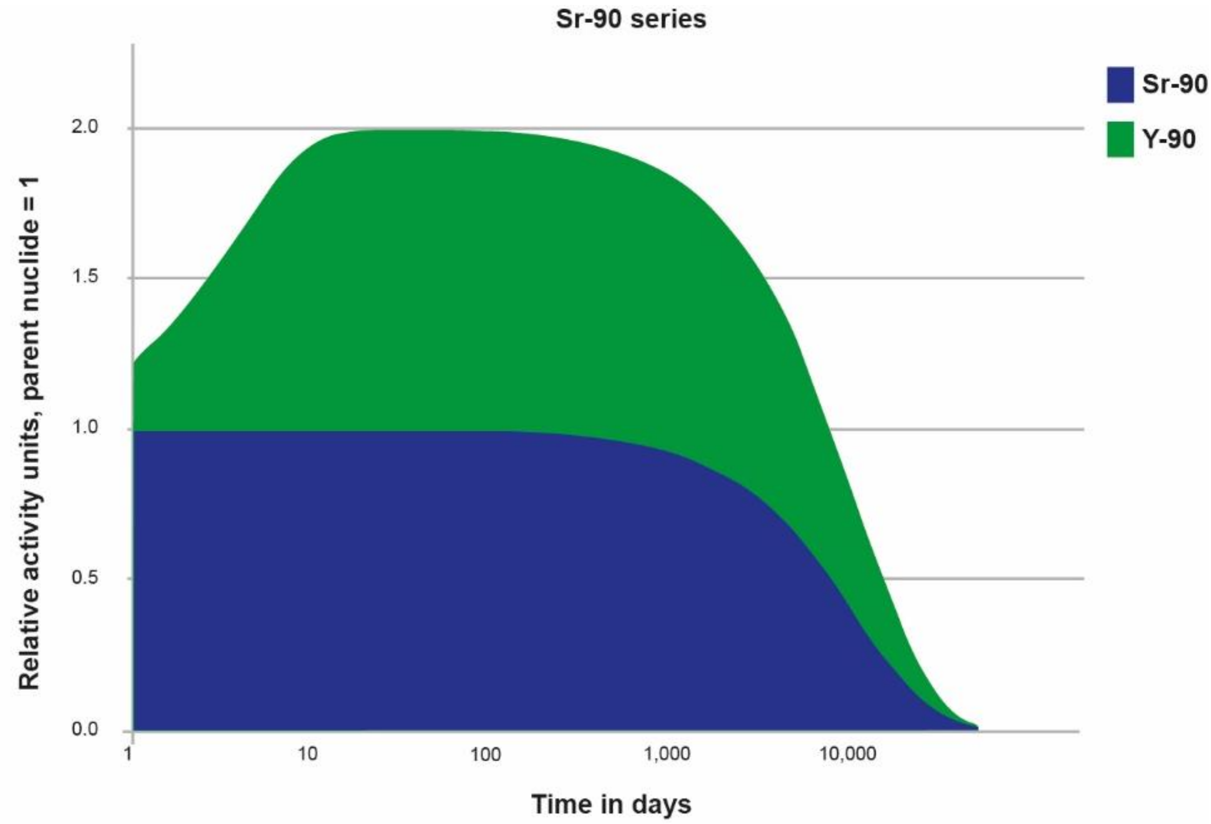

Fig. A-1: Development of total activity over time of a Sr-90/Y-90 radionuclide mixture calculated using the decay calculator (WISE 2012).

Figure A-2 is a second example showing the development of radionuclide Ac-227 with a range of daughter nuclides where maximum total activity occurs after around 190 days.

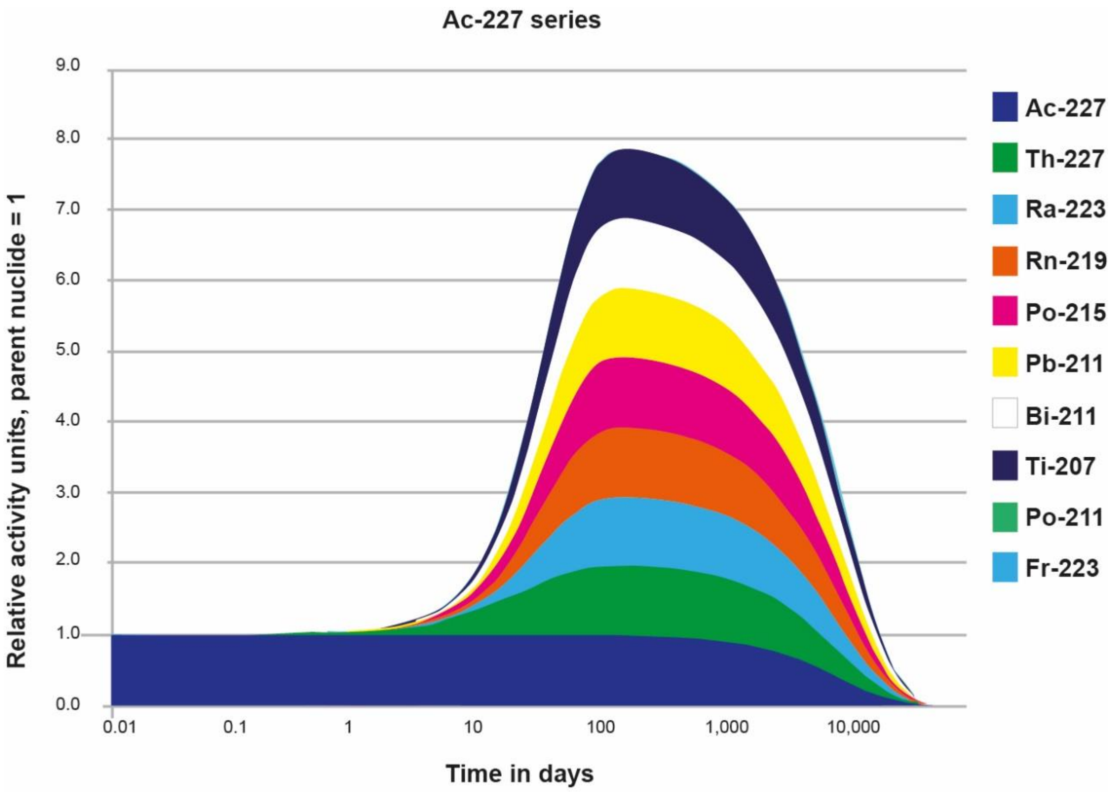

Fig. A-2: Total activity over time for the Ac-227 decay series calculated using the decay calculator (WISE 2012).

Total activity $A_G(t)$ at time t is thus

$$A_G(t) = \sum_{r=1}^{n} A_r(t) = \sum_{r=1}^{n} p_r(t) \cdot A_G(t) \tag{A-1}$$

where

$A_r(t)$ is the activity of the r-th radionuclide in the decay chain at time t

$p_r(t)$ is the relative proportion of the r-th radionuclide of total activity.

The activity $A_r(t)$ of the r-th radionuclide in the decay chain at time t is provided by (Eckerman and Ryman 1993, Health Canada 1999, Skrable et al. 1974) using (Bateman-equations)

$$A_r(t) = A_1(0) \cdot \left[\prod_{j=1}^{r-1} \left(f_{j,j+1} \cdot \lambda_{j+1} \right) \right] \cdot \sum_{j=1}^{r} \frac{e^{-\lambda_j \cdot t}}{\prod_{\substack{k=1 \\ k \neq j}}^{r} \left(\lambda_k - \lambda_j \right)}, \tag{A-2}$$

where

$$\prod_{r=1}^{n} a_r = \begin{Bmatrix} a_1 \cdot a_2 \cdot \ldots \cdot a_n,\ if\ \ n \geq 1 \\ 1,\ if\ \ n = 0 \end{Bmatrix}$$ and

$A_1(0)$ is the parent nuclide activity at time 0

$f_{j,j+1}$ is the relative proportion of decays from member j to member $j+1$ in the decay chain

λ_j is the decay constant of radionuclide j.

At time $t=0$, only the pure parent nuclide is present and $A_r(t) = 0$ for $r > 1$. A mixture ratio of radioactive daughter nuclides occurs after decay time T_a. This is followed by exposure time T_e. In the dose calculations below, the time from T_a to $T_a + T_e$ is considered the prevailing exposure time for determining intervention levels for alpha or beta contaminations.

Here, age T_a of the underlying parent-daughter radionuclide mixture is set to the age of peak activity T_{max}, meaning that an individual age has been chosen for each decay series. The radionuclide selection also includes radionuclides whose activity only reaches maximum activity after an extremely long period of time. In this case, a radionuclide mixture age of 10 years is used as a basis for calculation.

Gamma emitting radionuclides may be present in the decay series. However, relevant radionuclides were still taken into account here since exposure to alpha or beta radiation may be of an equal or higher level than exposure to gamma radiation (see Annex A-6).

For gaseous daughter nuclides with a half-life of more than 1 minute (Rn-222), it is assumed they were kept in a sealed container up until their release. Their short-lived daughter nuclides are then also present and contribute to exposure in the event of an aerosol-bound release. In particular with the decay series of Ra-226, it is assumed that Rn-222 only partially emanates (50%) after a release. This proportion of the noble gas is carried away from the point of emanation by air and therefore no longer contributes to the dose. The remainder – together with the short-lived daughter nuclides of Rn-222 – contributes to the dose along with the longer-lived radionuclides Pb-210, Bi-210 and Po-210. Other than the previously mentioned radionuclides, only Pb-214 and Bi-214 are relevant to the dose, although this also depends on the exposure pathway.

Method to calculate the dose from external radiation

The dose-rate coefficients provided by (Eckerman and Ryman 1993) were used to calculate the dose from the exposure pathway external exposure of the skin due to radioactive material deposited on the ground. These dose-rate coefficients account for the beta radiation contribution to the skin dose and effective dose. The contribution made by the radioactive daughter nuclides was not included in these dose-rate coefficients and must therefore be calculated separately.

According to (Eckerman and Ryman 1993), the effective dose E caused by external radiation from a contaminated surface with early contamination of the parent nuclide $B_1(0)$ can be calculated by integrating equation A-2 as follows:

$$E(T_e) = B_1(0) \cdot \sum_{r=1}^{n} \left[g_{b,r,E} \cdot \prod_{j=1}^{r-1} \left(f_{j,j+1} \cdot \lambda_{j+1} \right) \cdot \sum_{j=1}^{r} \frac{1 - e^{-\lambda_j \cdot T_e}}{\lambda_j \cdot \prod_{\substack{k=1 \\ k \neq j}}^{r} \left(\lambda_k - \lambda_j \right)} \right] \tag{A-3}$$

where

$g_{b,r,E}$ is the dose rate coefficient (effective dose) for external radiation of contaminated ground for radionuclide r,

which can also be expressed as

$$E(T_e) = B_1(0) \cdot \sum_{r=1}^{n} \left[g_{b,r,E} \cdot \int_0^{T_e} \frac{B_r(t)}{B_1(0)} dt \right] \tag{A-4}$$

where

$B_r(t)$ is the surface contamination of the *r*-th radionuclide in the decay chain at time *t.*

The integrals can be calculated using the READEM program from the DCFPAK package (Eckerman and Leggett 1996).

In contrast to the above description, in the cases under consideration here, contaminations involving a mixture of parent nuclide and daughter nuclides present at time T_a are considered where exposure takes place until time $T_a + T_e$. The effective dose for exposure time T_e is thus

$$E(T_e) = B_1(0) \cdot \sum_{r=1}^{n} \left[g_{b,r,E} \cdot \left(\int_0^{T_a+T_e} \frac{B_r(t)}{B_1(0)} dt - \int_0^{T_a} \frac{B_r(t)}{B_1(0)} dt \right) \right]. \tag{A-5}$$

As under the circumstances considered here only the total surface contamination $B_G(T_a)$ is known at time T_a and not the surface contamination of the parent nuclide $B_1(0)$ at time $t=0$, the following equation is used as an equivalent to equation A-1:

$$B_1(0) = p_1(T_a) \cdot B_G(T_a) \cdot e^{\lambda_1 \cdot T_a} . \tag{A-6}$$

This leads to the following equation for the effective dose:

$$E(T_e) = p_1(T_a) \cdot B_G(T_a) \cdot e^{\lambda_1 \cdot T_a} \cdot \sum_{r=1}^{n} \left[g_{b,r,E} \cdot \left(\int_0^{T_a+T_e} \frac{B_r(t)}{B_1(0)} dt - \int_0^{T_a} \frac{B_r(t)}{B_1(0)} dt \right) \right]. \tag{A-7}$$

The relative proportions p_r that the individual radionuclides contribute to total surface contamination can also be calculated using the READEM program from the DCFPAK package (Eckerman and Leggett 1996).

The same method can be used to calculate the skin dose for direct skin contamination resulting from a mixture of parent and daughter nuclides. Dose-rate coefficients for contamination of the skin are provided in (SSK 2004).

Method to calculate the dose from incorporation

If radionuclides are absorbed from an environmental medium due to inhalation or ingestion (hereafter jointly referred to as incorporation), over a time interval from $t=0$ to $t= T_e$, the resulting effective dose for a radionuclide without radioactive daughter nuclides can be expressed as

$$E_{Ink}(T_e) = g_{Ink,r,E} \cdot U \cdot C_r(0) \cdot \frac{1 - e^{-\lambda_r \cdot T_e}}{\lambda_r} . \tag{A-8}$$

where

$g_{Ink,r,E}$ is the dose coefficient (effective dose) for inhalation or ingestion for radionuclide *r*

U is the incorporation rate from the environmental medium that is considered a constant

$C_r(0)$ is the activity of the time-dependent specific activity $C_r(t)$ of radionuclide *r* in the environmental medium at time 0.

If the radionuclide decays via a series of daughter nuclides during the time interval from $t=T_a$ to $t= T_e$, the effective dose from incorporation $E_{Ink}(T_e)$ can be expressed as an equivalent to equation A-7 as follows:

$$E_{Ink}(T_e) = p_1(T_a) \cdot U \cdot C_G(T_a) \cdot e^{\lambda_1 \cdot T_a} \cdot \sum_{r=1}^{n} \left[g_{Ink,r,E} \cdot \left(\int_0^{T_a+T_e} \frac{C_r(t)}{C_1(0)} dt - \int_0^{T_a} \frac{C_r(t)}{C_1(0)} dt \right) \right]. \quad \text{(A-9)}$$

where

$C_G(T_a)$ is the total specific activity of the radionuclides in the environmental medium at time T_a, i.e. at the beginning of the exposure time period (cf. equation A-7).

Available data

The decay series with the daughter nuclides and transition probabilities were taken from Table A.1 of the Federation Guide No. 12 (Eckerman and Rynam 1993) as well as the Nuclear Wallet Card (Tuli 2011):

The dose coefficients provided by (BMU 2001) were used to calculate the exposure pathways inhalation following resuspension and ingestion of contaminated soil constituents. The values of these dose coefficients correspond with those provided in the current ICRP publication 119 (ICRP 2012). They take account of the dose contribution made by the radioactive decay products from the time of incorporation.

The set of dose coefficients (BMU 2001) does not contain any entries for some of the short-lived daughter nuclides under consideration here. In such cases, these daughter nuclides are not taken into consideration for calculations.

The dose-rate coefficients in Table III.3 of the Federation Guide No. 12 cited above are used for the exposure pathway “external radiation” (of the skin) from radionuclides deposited on the ground. The dose-rate coefficients stated there account for both gamma and beta radiation. The values also underlie the DCFPAK package, the READEM program, (Eckerman and Leggett 1996) and DC PAK3 (Eckerman and Leggett 2008), and are output along with their results.

The dose-rate coefficients for the exposure pathway skin contamination were taken from Table 7.1 of the SSK publication Volume 43 (SSK 2004). Here, the respective contributions of the alpha radiation (alpha energies > 6 MeV), beta and gamma radiation are summarised in value I_c.

Special case: Uranium

Uranium isotopes almost never occur individually in separated form. Natural uranium is chemically separated in its natural isotopic composition. One Becquerel of natural uranium is equivalent to 0.489 alpha decays per second of U-238, 0.489 alpha decays per second of U-234 and 0.022 alpha decays per second of U-235. U-238 is in radioactive equilibrium with its daughter nuclides Th-234 and Pa-234m after around 100 days. U-235 reaches radioactive equilibrium with its daughter Th-231 after approximately 10 days. From a dosimetric perspective, the radionuclides involved in these two decay chains do not require any further consideration. The same applies to all of the daughter nuclides in the U-234 decay chain.

With U-5%, the proportion of U-235 in the uranium mixture is enriched to 5%. In general, enrichment leads to an increase in the proportion of isotopes with a lower mass. This therefore increases the specific activity (Bq/kg^{-1}) largely determined by U-234. Depleted uranium (U-dep or DU) means an increase in the proportion of U-238 and a decrease in the proportion of isotopes with a lower mass number. The specific activity is lower than that of U-nat.

The following activity proportions of U-234, U-235# and U-238# were assumed to calculate the dose conversion factors of U-nat, U-5% and U-dep (rounded to two decimal places):

Uranium isotope	**U-nat**	**U-nat**	**U-5%**	**U-5%**	**U-dep**	**U-dep**
Decay chains	**Mass in %**	**Activity in %**	**Mass in %**	**Activity in %**	**Mass in %**	**Activity in %**
U-234	0.0055	24.96	0.045	70.55	0.0009	5.23
U-235#	0.72	2.25	5.00	5.40	0.20	0.80
U-238#	99.28	72.79	94.96	24.05	99.80	93.97

The radioactive equilibrium of the uranium isotopes and daughter nuclides were taken into account when calculating activity proportions.

A-2 Modelling exposure from inhalation of resuspended radionuclides

If a release leads to contamination of surfaces, e. g. in an urban area, people may be exposed due to resuspension processes. Contamination deposited on surfaces is partially resuspended due to external causes such as wind, mechanical vibration or local air flows generated by pedestrians or vehicles. If these airborne particles have an aerodynamic diameter < 10 µm, they are considered respirable and can lead to exposure of individuals due to inhalation. In general, this exposure pathway only makes a minor contribution to total exposure following deposition since gamma emitting radionuclides are decisive in the event of an accident and because direct radiation contributes far more to exposure following deposition on surfaces.

Other circumstances can occur, in particular if alpha and/or beta emitting radionuclides are released without any significant proportion of gamma radiation.

The proportion of deposited activity (in Bq m^{-2}) per unit of time that becomes airborne again and leads to an activity concentration in the surrounding air (in Bq m^{-3}) is decisive when it comes to the air concentration that occurs due to resuspension of radionuclides that were deposited on paved and unpaved surfaces as well as vegetation. The initially resulting activity concentration close to the surface is subject to the turbulent diffusion processes and influence of the prevailing wind, and can therefore be transported to areas with little or no contamination.

A-2.1 Resuspension and airborne concentration

Two different parameters are generally used to describe resuspension processes: the resuspension rate and resuspension factor. The resuspension rate is better suited to immediately detecting resuspension processes. However, additional steps are still required to detect the airborne activity concentration for contaminated surfaces or outdoor areas.

In terms of a given area contaminated with radioactive material, the resuspension rate *RR* in s^{-1} is defined as follows:

$$RR = \frac{\mathit{Resuspension\ flow}\ [Bq\ m^{-2}\ s^{-1}]}{\mathit{Surface\ contamination}\ [Bq\ m^{-2}]}. \qquad \text{(A-10)}$$

It shows the proportion of contamination present on a given surface per unit of time that is transferred to an airborne state. This provides a direct measurement for a source term released by the surface. In experiments involving such contaminated surfaces, such as a wind tunnel, this parameter and its dependency are determined by influencing factors such as wind flow, particle size, surface properties and time. The resuspension rate *RR* is often expressed using the unit $[h^{-1}]$. By way of example, $RR = 10^{-4}\ h^{-1}$ means that a proportion of 10^{-4} of contamination on the contaminated surface becomes airborne within one hour. The level of resuspension rate depends, in particular, on the strength of the air flow upon the contaminated surface (wind speed), local effects to air flow caused by pedestrians or vehicles, and on the effect of mechanical vibrations. Experiments showed that following deposition of particulate material, the resuspension rate decreases significantly over time. The reason for this is that over time, the weakly bound particles are successively replaced on the surface, and processes occur which lead to increasing adhesion to the surface.

In light of this, the resuspension factor *RF* in m^{-1} is defined as follows:

$$RF = \frac{\mathit{Airborne\ activity\ concentration\ as\ a\ result\ of\ resuspension}\ [Bq\ m^{-3}]}{\mathit{Surface\ contamination}\ [Bq\ m^{-2}]}. \qquad \text{(A-11)}$$

The resuspension factor is generally determined using field measurements by setting a large-scale and more or less homogeneously distributed surface contamination in relation to airborne concentration. In general, such measurements are based on very long averaging times, meaning that the resuspension factor determined this way measures an averaged equilibrium state resulting from effective environmental conditions such as prevailing wind speeds, weather conditions or other mechanical conditions such as vibrations or abrasion over prolonged periods of time. Corresponding measurements after a contamination incident, e. g. the Chernobyl accident, have mostly not been performed until a later phase, meaning that there are only a few environmental resuspension factor measurements available for the early phase.

With respect to this problem, the NRPB report (Walsh 2002) provides an excellent overview of relevant measurements concerning the resuspension factor and its time dependency. The report recommends the following parameters and time dependency for the resuspension factor (in m^{-1}) following an acute, widespread contamination incident in non-arid conditions such as those prevalent in north-western Europe (e. g. Great Britain or Germany):

$$RF(t) = \frac{RF(0) \cdot T_B}{t} + RF(T). \qquad \text{(A-12)}$$

where

t is the time following deposition in days [d]

T_B is the reference time in relation to *t* ($T_B = 1$ d)[20]

RF (0) is the proposed value for the resuspension factor on the 1st day (= $1.2\ 10^{-6}\ m^{-1}$)

RF(T) is the proposed value for the resuspension factor as a long-term value (= $10^{-9}\ m^{-1}$) (This proportion of the resuspension factor only becomes relevant from a quantitative perspective after approx. $T = 2.5$ years).

[20] The reference time T_B is not stated in the original publication. It was introduced here to provide formally correct dimensions.

This ratio proposed by Garland is based on field measurements that were generally introduced (weeks, months, years) after a widespread contamination incident as well as on measurements involving large wind tunnels which also measured the early phase from the first few hours up to several months (Garland 1979, Garland 1982).

As already described, measured resuspension factors *RF* are generally averaged over prolonged periods and thus for differing weather conditions such as wind speed, temperature and humidity. For this reason, a resuspension factor that applies to short-term environmental conditions is subject to temporal variations.

A resuspension factor can also be defined for limited areas contaminated by the deposition of released contaminants if the airborne (activity) concentration determined by means of measurements or suitable modelling is set in relation to the concentration per area. Measuring the air concentration caused by resuspension of a contaminated surface can be performed by taking the parameters into account together with the resuspension rate *RR*. The decisive factors here are insights into the resuspension rate as a function of influencing parameters such as wind speed, time since the onset of contamination, other influences caused by pedestrians or vehicles, and possibly mechanical vibrations. As a result of this, the next section provides insights into the level and time dependency of the resuspension rate.

A-2.2 On the level and time dependency of resuspension processes during the early phase

The article published by Loosmore (2003) provides details of particulate material in the first few minutes and hours after deposition has taken place. It analyses data from several wind-tunnel experiments conducted by other authors to measure resuspension rates and adapts the data by means of various (empirical) models. The measured and adapted data refer to respirable particles with aerodynamic diameters of < 10 µm. In spite of the variation of the compiled data, they indicate a temporal decrease in the resuspension rate *RR(t)* in line with the ratio:

$RR(t) \sim B_r\ t{-}\nu$ (where $\nu \approx 1$). (A-13)

Loosmore’s data analysis therefore supports the time dependency of resuspension processes due to the influence of wind as proposed by Walsh (2002) and expressed for the resuspension factor in equation (A-12), and also particularly applies to times shortly after the onset of an outdoor contamination.

Recently published investigations (Koch et al. 2012) represent a major improvement in terms of available data on resuspended proportions per exposure or exposure time (resuspension rate *RR*). The aim was to perform experiments to determine resuspension data for particulate radioactive material of relevant contaminated surfaces in radiological emergencies in order to assess the exposure of emergency workers and affected persons due to resuspension. The measurements focussed on the resuspension of respirable particles with aerodynamic diameters of < 10 µm.

The resuspension rates measured over a period of 2 to 3 hours after the onset of wind influence also showed a time dependency in line with equations (A-12) and (A-13) where ν is almost 1. The influencing air flow speed over the test surface covered with dust exhibited a resuspension rate dependency increase to the power of 2.5 ($RR \sim u^{2,5}$). Other test conditions such as properties of the surfaces covered with dust or different types of dust had little impact on the results.

As well as the measured resuspension rates, (Koch et al. 2012) also analysed scenarios in which larger areas, e. g. urban areas, were contaminated with radioactive dust. Airborne concentrations were determined for average atmospheric dispersion conditions and a somewhat elevated wind speed in order to arrive at a corresponding resuspension factor *RF*.

In summary, these results support the resuspension factor *RF* proposed in (Walsh 2002) and expressed in equation (A-12). The time dependency proportional to *1/t* takes effect shortly after deposition. As a result, wind resuspension leads to as much resuspended dust in the first hour as is resuspended in total in the following 23 hours. This means that measures carried out early on to suppress resuspension, e. g. spraying contaminated surfaces, are a highly effective way of reducing exposure via the inhalation pathway due to resuspension.

The parameters and temporal dependency of the resuspension factor recommended by Walsh in equation (A-12) form the basis for deriving intervention levels in this report. The assumed temporally constant value $RF(0) = 1.2 \cdot 10^{-6}$ m^{-1} for the first day provided there can be considered conservative due to resuspension rate measurement results provided by (Koch et al. 2012) and the model calculations for contamination situations carried out there.

A-2.3 Dose calculation

The nuclide-specific effective dose due to inhalation of resuspended radioactive particle E_r in mSv is calculated as the product of the time-integrated radionuclide concentration in the air, the respiration rate and nuclide-specific dose coefficients, where the radionuclide concentration in the air is determined by the initial activity on the ground $B_r(0)$ in Bq m^{-2} multiplied by the resuspension factor discussed above (equation A-12):

$$E_r = \dot{V} \cdot g_{h,r,E} \cdot B_r(0) \cdot \left[\int_0^{T_e} \left(RF(0) \cdot \frac{T_B}{t} + RF(T) \right) \cdot \exp(-\lambda_r t)\, dt \right] \cdot 1{,}000 \,. \qquad \text{(A-14)}$$

Here is an explanation of the symbols not already explained above:

$\dot{V}$	is the respiration rate in m^3 d^{-1} (dependent upon age group)
T_e	is the exposure period in d
T_B	is the formal parameter for dimension correction in d (T_B= 1 d)
r	is the index for individual radionuclides (without considered daughter nuclides)
λ_r	is the decay constant for radionuclide r in d^{-1}
$g_{h,r,E}$	is the dose coefficient (effective dose) for inhalation in Sv Bq^{-1}.

The factor of 1,000 includes the conversion from Sv to mSv.

The integral

$$\int^{7d} RF(T) \cdot \exp(-\lambda_r t)\, dt \qquad \text{(A-14a)}$$

is negligible over an integration period of 7 days when compared with the integral

$$\int^{7d} RF(0) \cdot \frac{T_B}{t} \cdot \exp(-\lambda_r t) dt \,. \qquad \text{(A-14b)}$$

The maximum levels for normal members of the public in the age groups adult and small children up to the age of 1 year as provided by (BMU 2001) are used for the dose coefficients and take into consideration the daughter nuclides that arise during the commitment period.

The integral in equation (A-14b) can be expressed and numerically evaluated (Walsh 2002) using the following exponential integral function:

$$E_1(x) = \int_x^{\infty} t^{-1} \cdot e^{-t} dt \quad . \qquad \text{(A-15)}$$

Both the integrand and the exponential integral function $E_1(x)$ are undefined for x = 0 (Abramowitz and Stegun 1964). The approach taken by Walsh (2002) is therefore used as an auxiliary measure by assuming that dependency of the resuspension factor on time (t^{-1}) is disregarded on the first day.

This approximation, together with several substitutions, can be expressed as follows:

$$\int_0^{T_e} \frac{e^{-\lambda t} \cdot T_B}{t} dt \approx \int_0^{1d} e^{-\lambda t} dt + \int_{1d}^{\infty} \frac{e^{-\lambda t} \cdot T_B}{t} dt - \int_{T_e}^{\infty} \frac{e^{-\lambda t} \cdot T_B}{t} dt , \qquad \textit{(A-16)}$$

$$\int_0^{T_e} \frac{e^{-\lambda t} \cdot T_B}{t} dt \approx \frac{1 - e^{-\lambda \cdot 1d}}{\lambda} + T_B \left[E_1(\lambda \cdot 1d) - E_1(\lambda \cdot T_e) \right] . \qquad \textit{(A-16a)}$$

The expression on the right-hand side of equation A-16 is abbreviated to *ExpInt* (λ, T_e) hereinafter.

As a result, the equation for the effective dose E_r in mSv from an individual nuclide *r* is as follows:

$$E_r = \dot{V} \cdot g_{h,r,E} \cdot B_r(0) \cdot RF(0) \cdot ExpInt\ (\lambda_r, T_e) \cdot 1{,}000 \quad . \qquad \textit{(A-17)}$$

Due to numerical integration, the dose for parent-daughter radionuclide mixtures of a decay series cannot be calculated here by adding up the decays of all daughter nuclides given in equation A-2. However, with short-lived daughter nuclides in radioactive equilibrium with a longer-lived parent nuclide, it can be approximately assumed that the activities of the daughter nuclides change with the half-life of the parent nuclide.

This approximation only leads to minor deviations from the exact level for the radionuclide mixture age T_{max} (see Annex A-1) and integration time (T_e = 7 d) selected here. For this reason, the decay constant of the *r*-th radionuclide is replaced by the decay constant of the parent nuclide λ_1 and the dose contributions of all the radionuclides present in the decay chain at time T_a are added up. This in turn provides the total inhalation dose *E* in mSv resulting from resuspended radionuclides from

$$E = \dot{V} \cdot RF(0) \cdot B_G(T_{max}) \cdot ExpInt\ (\lambda_1, T_{exp}) \cdot \sum_{r=1}^{n} g_{h,r,E} \cdot p_r(T_{max}) \cdot 1{,}000 \qquad \text{(A-18)}$$

where

r	is the index of the parent and daughter nuclides to be taken into account
$p_r(T_{max})$	is the proportion of radionuclide *r* of the total ground contamination $B_G(T_a)$ at time T_a.

The definitions provided above and in Annex A-1 continue to apply.

A-2.4 Results of the "inhalation due to resuspended radionuclides" calculations

Radionuclide	**Max. normed dose** mSv (eff. dose) relating to 1 Bq m^{-2}	**Operational intervention level of ground contamination** in Bq m^{-2} relating to 10 mSv (eff. dose)
Beta emitters		
P-32	2.4E-10	4.2E+10
P-33	1.1E-10	9.0E+10
S-35	1.5E-10	6.8E+10
Ca-45	2.9E-10	3.5E+10
Ni-63	1.0E-10	9.8E+10
Sr-89	6.0E-10	1.7E+10
Sr-90#	6.3E-09	1.6E+09
Y-90	7.3E-11	1.4E+11
Pr-143	1.7E-10	5.9E+10
Pm-147	3.9E-10	2.6E+10
Er-169	6.7E-11	1.5E+11
Tm-170	5.4E-10	1.8E+10
Tl-204	3.1E-11	3.3E+11
Bi-210	5.5E-09	1.8E+09
Alpha emitters		
Po-210	3.3E-07	3.0E+07
Ra-223#	3.0E-07	3.3E+07
Ra-226#	2.5E-07	4.1E+07
Ac-225#	2.0E-07	5.1E+07
Ac-227#	1.1E-05	9.0E+05
Th-227#	4.6E-07	2.2E+07
Th-228#	8.5E-07	1.2E+07
Th-229#	4.0E-06	2.5E+06
U-234	7.4E-07	1.4E+07
U-235#	3.3E-07	3.0E+07
U-238#	3.1E-07	3.2E+07
U-nat#	4.2E-07	2.4E+07
U-5%#	6.1E-07	1.6E+07
U-dep#	3.4E-07	3.0E+07
Pu-238	8.6E-06	1.2E+06
Pu-239	9.4E-06	1.1E+06
Pu-240	9.4E-06	1.1E+06
Am-241	7.5E-06	1.3E+06
Cm-242	4.6E-07	2.2E+07
Cm-244	4.5E-06	2.2E+06
Cf-252	1.6E-06	6.4E+06

A-3 Modelling exposure from external radiation due to contaminated ground

A-3.1 Dose calculation for radionuclides without radioactive daughter nuclides

The effective dose from external radiation due to contaminated ground is calculated as follows:

$$E_r = B_r(0) \cdot g_{b,r,E} \cdot \frac{1 - e^{-\lambda_r \cdot T_e}}{\lambda_r} \cdot 1{,}000 \cdot 86{,}400 \qquad \text{(A-19)}$$

where

E_r	is the effective dose from radionuclide *r* in mSv,
$B_r(0)$	is the ground contamination for radionuclide *r* at time t=0 in Bq m^{-2},
$g_{b,r,E}$	is the dose rate coefficient (effective dose) for external radiation from contaminated ground for the radionuclide *r* in Sv s^{-1} Bq^{-1} m^2, from (Eckerman and Ryman 1993),
λ_r	is the decay constant for radionuclide *r* in d^{-1},
T_e	is the exposure period in d,
1,000	is the conversion factor from Sv to mSv,
86,400	is the conversion factor from s to d.

A-3.2 Dose calculation for parent-daughter radionuclide mixtures

Derivation of the effective dose for parent-daughter radionuclide mixtures was already described in Annex A-1.

A-3.3 Results of the calculations "External radiation from the ground"

Radionuclide	**Max. normed dose** in mSv (eff. dose) relating to 1 Bq m^{-2}	**Operational intervention level of ground contamination** in Bq m^{-2} relating to 10 mSv (eff. dose)
	Beta emitters	
P-32	4.4E-08	2.3E+08
P-33	2.0E-11	5.0E+11
S-35	7.8E-12	1.3E+12
Ca-45	2.2E-11	4.5E+11
Ni-63	see *	
Sr-89	4.0E-08	2.5E+08
Sr-90#	3.4E-08	3.0E+08
Y-90	3.1E-08	3.3E+08
Pr-143	1.0E-08	9.5E+08
Pm-147	1.7E-11	5.9E+11
Er-169	3.2E-11	3.1E+11
Tm-170	1.6E-08	6.4E+08
Tl-204	6.5E-09	1.5E+09
Bi-210	1.4E-08	7.4E+08

Radionuclide	**Max. normed dose** in mSv (eff. dose) relating to 1 Bq m^{-2}	**Operational intervention level of ground contamination** in Bq m^{-2} relating to 10 mSv (eff. dose)
Alpha emitters		
Po-210	4.8E-12	2.1E+12
Ra-223#	3.0E-08	3.3E+08
Ra-226#	7.4E-08	1.4E+08
Ac-225#	2.1E-08	4.8E+08
Ac-227#	3.5E-08	2.8E+08
Th-227#	4.0E-08	2.5E+08
Th-228#	1.2E-07	8.1E+07
Th-229#	1.9E-08	5.4E+08
U-234	3.5E-10	2.8E+10
U-235#	4.7E-08	2.1E+08
U-238#	2.4E-08	4.1E+08
U-nat#	1.9E-08	5.3E+08
U-5%#	8.7E-09	1.1E+09
U-dep#	2.3E-08	4.3E+08
Pu-238	3.8E-10	2.6E+10
Pu-239	1.7E-10	5.8E+10
Pu-240	3.6E-10	2.8E+10
Am-241	1.4E-08	7.1E+08
Cm-242	4.2E-10	2.4E+10
Cm-244	3.9E-10	2.6E+10
Cf-252	3.2E-10	3.2E+10

* No dose-rate coefficients due to low beta energy as stated in (SSK 2004).

A-4 Radiation exposure due to skin contamination

Skin contamination can lead to an external dose in the radiation-sensitive layer of epidermal basal cells. Another possibility is that part of the contamination comes from touching the mouth with the hand, with contamination then passing to the ingestion tract and leading to an ingestion dose. The dose-related intervention levels for personal decontamination in Section 7.2 are recommended for both of these pathways. The intervention level is 50 mSv (equivalent dose) for the external skin dose and 1 mSv effective dose for the ingestion dose.

A-4.1 Estimating the skin dose

In order to estimate the skin dose, it is assumed that activity only occurs on the surface of the skin. A depth of 50 µm to 100 µm of the basal cell layer of the epidermis considered sensitive to radiation is assumed for calculations. Radioactive material can penetrate the stratum corneum, yet the activity concentration decreases exponentially with a half-value layer of 2 µm (SSK 1989). Penetration only has a minor impact on the dose to the skin layer sensitive to radiation, and, accordingly, penetration of contamination into the stratum corneum is not covered here.

The skin's stratum corneum is in a constant state of renewal. According to (Apostoaei and Kocher 2010) and (Grove and Kligman 1983), the cell renewal period for a healthy epidermis is between 17 d and 36 d. As a result, activity on the skin also decreases rapidly without performing decontamination measures. Regular cleansing of the skin, e. g. by showering on a daily basis, also helps to reduce residual activity on the skin. According to a model from (Apostoaei and Kocher 2010), showering on a daily basis reduces contamination of the skin significantly with every shower:

$$\alpha_j = 1 - (\gamma_j + \beta)$$

where

α_j is the tiny fraction of activity remaining on the skin after the *j*-th shower (α_j refers to activity on the skin prior to each shower),

γ_j is the tiny fraction of activity removed with every *j*-th shower,

β is the tiny fraction of activity removed by desquamation with every *j*-th shower, $\beta = 0.033$.

The fraction of activity remaining on the skin after the *j*-th shower is thus $\alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \ldots \cdot \alpha_j$.

The activity remaining on the skin is largely determined by the parameters γ_j. If initial cleaning after a deployment or contamination is performed efficiently and followed up by regular showers, the parameter set provided by (Apostoaei and Kocher 2010)

γ_1=0.8, γ_2=0.35, γ_3=0.1, γ_4=0.02, γ_5=0.02 …

and the assumption of showering once per day lead to activity on the skin that is less than 10% of the initial activity after three days and less than 2% of the initial activity after four weeks.

By taking the effect of decontamination into consideration, it can be seen that the total number of decays of a radionuclide on the skin is not higher after several months than the number of decays in 3 days, based on the assumption of not performing decontamination. For this reason and for the sake of simplicity, the dose calculation is based on activity assumed to have spent three days on the skin without any reduction in activity due to skin renewal and decontamination.

The local skin equivalent dose H_S at a depth of 0.07 mm (in mSv) results in the following equation for individual nuclides:

$$H_S(0.07) = A_r \cdot \frac{1 - e^{-\lambda_r \cdot T_e}}{\lambda_r} \cdot I_{c,r} \cdot 0.024 \qquad \text{(A-20)}$$

where

A_r is the activity per area of radionuclide *r* on the skin upon commencement of contamination (in Bq cm^{-2}),

λ_r is the decay constant for radionuclide *r* in d^{-1},

T_e is the period of time activity spends on the skin in d, here $T_e = 3\ d$

$I_{c,r}$ is the skin equivalent dose-rate coefficient according to (SSK 2004) in µSv h^{-1} Bq^{-1} cm^2, where $I_{c,r} = I_{c\alpha,r} + I_{c\beta,r} + I_{c\gamma,r}$ for the contributions of the three radiation types on the equivalent dose rate made by radionuclide *r*,

0.024 is the conversion factor from µSv to mSv and from h to d.

If the radionuclide on the skin decays to a decay chain with daughter nuclides, the local skin equivalent dose (in mSv) can be calculated using equation A-7 based on the method provided in Annex A-1:

$$H_S(T_e) = p_1(T_a)\cdot A_G(T_a)\cdot e^{\lambda_1 \cdot T_a}\cdot \sum_{r=1}^{n} I_{c,r}\cdot\left[\int_0^{T_a+T_e}\frac{A_r(t)}{A_1(0)}dt - \int_0^{T_a}\frac{A_r(t)}{A_1(0)}dt\right]\cdot 0.024 \qquad \text{(A-21)}$$

where

$p_1(T_a)$ is the proportion of the parent nuclide relative to total activity upon commencement of the contamination

$A_G(T_a)$ is the total activity per area on the skin upon commencement of contamination (in Bq cm^{-2})

T_a is the age of the radionuclide mixture upon commencement of exposure in d.

Considerations by Rohloff and Heinzelmann (1996) and Eatough (1997) have shown that alpha particles with energies > 6 MeV are in fact able to penetrate through to the sensitive epidermal basal cells, and must therefore be taken into account when calculating the dose (see also ICRP 2010, Annex G). Some of the radionuclides discussed here decay to short-lived daughter nuclides that emit high-energy alpha particles such as Po-212 which emits 8.8 MeV. The dose-rate coefficients for the skin provided by (SSK 2004) are listed separately by radiation type. Accordingly, the skin dose from high-energy alpha radiation of around 6.5 MeV or more can exceed the skin dose from typical beta emitters by more than two orders of magnitude.

Using A_r =1 Bq cm^{-2} and $A_G(T_a)$ = 1 Bq cm^{-2}, H_S can be expressed as the dose conversion factor in mSv Bq^{-1} cm^2. Together with the dose-related intervention level of 50 mSv recommended in Section 7.2, the operational intervention level B_S in Bq cm^{-2} can be expressed as

$$B_S = \frac{50\ mSv}{H_S}\ . \qquad \text{(A-22)}$$

The results of these calculations are provided in Table A-5.1.

A-4.2 Ingestion dose resulting from a skin – hand – mouth-transfer of activity

In the event of contamination of the skin or clothing, it cannot be ruled out that part of the activity ends up in the digestive system due to touching the contaminated area of skin and then touching the mouth, which in turn leads to an ingestion dose. For this reason, it must be investigated whether the ingestion dose needs to be taken into consideration when stipulating intervention levels as a trigger criterion for personal decontamination.

To this end, a simple model and the model parameters adapted to this question are used to determine the (effective) ingestion dose E_g: The model is devised on the basis of that of (Deckert et al. 2000) (exception: exposure time), which was used to derive the surface contaminations in Table 1 Column 4 of Annex III of the German Radiation Protection Ordinance (StrlSchV 2001).

The fact that emergency workers (should) wear face masks during their work, which would make ingestion far more difficult, is not taken into account here. The radioactive decay and build-up of daughter nuclides during exposure are also disregarded here.

$$E_g = A_G \cdot \sum_r p_r \cdot g_{g,r,E} \cdot f \cdot I \cdot \Delta T \cdot 1{,}000 \qquad \text{(A-23)}$$

where

A_G is the total activity per area for all radionuclides r in Bq cm^{-2} (set to 1 Bq cm^{-2} in order to calculate the dose conversion factor)

p_r	is the proportion of radionuclide r in the parent-daughter radionuclide mixture; with individual nuclides, r and p_r set to 1
$g_{g,r,E}$	is the ingestion dose coefficient (effective dose) for adults for radionuclide r in Sv Bq^{-1}.
f	is the transfer factor: skin(/clothing)-hand-mouth (= 0.01)
I	is the rate of contact with the contaminated surface (= 1.25 cm^2 h^{-1})
ΔT	is the exposure time (= 72 h or 3 days). The duration of exposure is described in Section A-4.1
1,000	is the conversion from Sv to mSv.

Using A_G =1 Bq cm^{-2}, E_g can be expressed as the dose conversion factor in mSv Bq^{-1} cm^2. In terms of the intervention level for the ingestion dose of 1 mSv effective dose, the operational intervention level B_g can be calculated as an inverse value of E_g.

The result of these calculations are also available in Table A-4.1.

A-4.3 Intervention levels

Considerations regarding skin dose and ingestion dose due to contamination of the skin and the resulting intervention levels for personal decontamination are summarised by nuclide in Table A-4.1 and by nuclide group in Table A-4.2.

Table A-4.1 provides three different nuclide groups:

- Beta emitters
- Alpha emitters or decay series with alpha energies > 6.5 MeV The beta emitting radionuclide Ac-227# can be included in this group because the decay chains largely match those of various high-energy alpha emitters. All of the radionuclides in this group have gamma emitting daughter nuclides, but the highest skin dose contributions come from high-energy alpha emitting daughter nuclides such as Po-212, Po-213, Po-215 and At-217.
- Alpha emitters or decay series with alpha energies < 6.5 MeV

The final column contains nuclide-specific intervention levels obtained by rounding up the values in the second-to-last column to full orders of magnitude. The lowest intervention for each of the three radionuclide groups should be used to decide whether personal decontamination is necessary (see Table A-4.2).

Table A-4.1: Compilation of nuclide-specific calculations for skin contamination intervention levels.

H_S is the dose conversion factor used to calculate the skin dose, B_S is the operational intervention level of activity per area for external exposure to the skin, E_g is the dose conversion factor for ingestion via the skin-hand-mouth pathway, and B_g is the operational intervention level for ingestion.

Radionuclide	H_S in mSv relating to 1 Bq cm^{-2}	B_s in Bq cm^{-2} relating to 50 mSv for the skin	E_g in mSv relating to 1 Bq cm^{-2}	B_g in Bq cm^{-2} relating to 1 mSv eff. dose	B_S or B_g minimum of columns 3 and 5 in Bq cm^{-2} relating to 50 mSv skin dose or 1 mSv eff. dose	B_s or B_g (column) rounded in Bq cm^{-2} relating to 50 mSv skin dose or 1 mSv eff. dose
1	2	3	4	5	6	7
Beta emitters						
P-32	1.07E-01	4.66E+02	2.16E-06	4.63E+05	4.66E+02	100
P-33	5.39E-02	9.27E+02	2.16E-07	4.63E+06	9.27E+02	1,000
S-35	2.28E-02	2.20E+03	1.17E-07	8.55E+06	2.20E+03	1,000
Ca-45	5.58E-02	8.96E+02	6.39E-07	1.56E+06	8.96E+02	1,000
Ni-63	See *		1.35E-07	7.41E+06	-	10,000,000
Sr-89	1.13E-01	4.43E+02	2.34E-06	4.27E+05	4.43E+02	100
Sr-90#	1.08E-01	4.63E+02	1.38E-05	7.24E+04	4.63E+02	100
Y-90	8.00E-02	6.25E+02	2.43E-06	4.12E+05	6.25E+02	1,000
Pr-143	1.00E-01	4.99E+02	1.08E-06	9.26E+05	4.99E+02	100
Pm-147	4.03E-02	1.24E+03	2.34E-07	4.27E+06	1.24E+03	1,000
Er-169	6.33E-02	7.90E+02	3.33E-07	3.00E+06	7.90E+02	1,000
Tm-170	1.14E-01	4.38E+02	1.17E-06	8.55E+05	4.38E+02	100
Tl-204	1.01E-01	4.96E+02	1.08E-06	9.26E+05	4.96E+02	100
Bi-210	9.43E-02	5.30E+02	1.17E-06	8.55E+05	5.30E+02	1,000
Alpha emitters or decay series with alpha energies > 6.5 MeV						
Ra-223#	8.87E+00	5.64E+00	1.50E-05	6.66E+04	5.64E+00	10
Ra-226#	4.03E+00	1.24E+01	1.01E-04	9.88E+03	1.24E+01	10
Ac-225#	1.77E+01	2.82E+00	3.66E-06	2.73E+05	2.82E+00	1
Ac-227#	7.28E+00	6.86E+00	1.36E-04	7.36E+03	6.86E+00	10
Th-227#	8.25E+00	6.06E+00	1.39E-05	7.19E+04	6.06E+00	10
Th-228#	1.30E+01	3.84E+00	1.84E-05	5.43E+04	3.84E+00	1
Th-229#	1.46E+01	3.43E+00	6.90E-05	1.45E+04	3.43E+00	1
Alpha emitters or decay series with alpha energies < 6.5 MeV						
Po-210	3.72E-08	1.35E+09	1.08E-03	9.26E+02	9.26E+02	1,000
U-234	4.03E-04	1.24E+05	4.41E-05	2.27E+04	2.27E+04	10,000
U-235#	8.06E-02	6.20E+02	2.13E-05	4.69E+04	6.20E+02	1,000
U-238#	4.64E-02	1.08E+03	1.45E-05	6.89E+04	1.08E+03	1,000
U-nat#	3.47E-02	1.44E+03	2.21E-05	4.53E+04	1.44E+03	1,000

Radionuclide	H_S in mSv relating to 1 Bq cm^{-2}	B_s in Bq cm^{-2} relating to 50 mSv for the skin	E_g in mSv relating to 1 Bq cm^{-2}	B_g in Bq cm^{-2} relating to 1 mSv eff. dose	B_S or B_g minimum of columns 3 and 5 in Bq cm^{-2} relating to 50 mSv skin dose or 1 mSv eff. dose	B_s or B_g (column) rounded in Bq cm^{-2} relating to 50 mSv skin dose or 1 mSv eff. dose
1	2	3	4	5	6	7
U-5%#	1.33E-02	3.75E+03	3.58E-05	2.80E+04	3.75E+03	1,000
U-dep#	4.39E-02	1.14E+03	1.61E-05	6.20E+04	1.14E+03	1,000
Pu-238	2.09E-04	2.39E+05	2.07E-04	4.83E+03	4.83E+03	1,000
Pu-239	5.83E-05	8.57E+05	2.25E-04	4.44E+03	4.44E+03	1,000
Pu-240	2.02E-04	2.48E+05	2.25E-04	4.44E+03	4.44E+03	1,000
Am-241	1.08E-03	4.63E+04	1.80E-04	5.56E+03	5.56E+03	10,000
Cm-242	2.15E-02	2.33E+03	1.08E-05	9.26E+04	2.33E+03	1,000
Cm-244	1.30E-04	3.86E+05	1.08E-04	9.26E+03	9.26E+03	10,000
Cf-252	5.39E-02	9.27E+02	8.10E-05	1.23E+04	9.27E+02	1,000

* No dose-rate coefficients due to low beta energy as stated in (SSK 2004)

Table A-4.2: Intervention levels of the measured activity per area on the skin and/or clothing (in Bq cm^{-2}) which, if exceeded, should trigger personal decontamination. Basis: Dose-related intervention level of 50 mSv for the skin dose and 1 mSv for the effective dose due to ingestion via the skin-hand-mouth pathway.

Exposure situation	Radionuclide group	Intervention level
	Beta emitters other than Ac-227#	100 Bq cm^{-2}
Emergency exposure situation and subsequent existing exposure situation	Alpha emitters or decay series with alpha energies > 6.5 MeV and Ac-227#	1 Bq cm^{-2}
	Alpha emitters or decay series with alpha energies < 6.5 MeV	1,000 Bq cm^{-2}

A-5 Unintentional ingestion

A-5.1 Question

Unintentional ingestion is a situation where ground or object contamination is present and in which activity is fully or partially transferred to the mouth, albeit with some degree of difficulty. This may occur, for example, by a person's hand coming into contact with contaminated ground or a contaminated object and then touching the area around the mouth and subsequently transferring part of the facial contamination to the mouth. Another example is where a child plays in a contaminated sandpit and puts sand in its mouth. Any foodstuffs stored openly (e. g. fruit) that have been contaminated by a passing radioactive cloud and then consumed can lead to an ingestion dose.

In general, a model can be formulated to describe the relationship between contamination *B* and ingestion dose E_g:

$E_g = TF \cdot B$

where *TF* is the transfer factor.

The transfer factor may depend on a number of variables, such as the contamination sticking to the ground or objects, the frequency and area of contact, the frequency of contact with the area around the mouth, and of course the radionuclide properties (e. g. composition of the radionuclide mixture, half-lives, dose coefficients). It is not possible to provide a general transfer factor size estimate.

The following example involves a child playing in a recently contaminated sandpit and putting sand into its mouth.

The contamination involves alpha/beta emitters. Here, the task is to investigate whether the dose resulting from ingestion of soil constituents is worthy of separate consideration in comparison to other exposure pathways.

The exposure situation is characterised by the fact that (contaminated) soil constituents inadvertently enter the reference person's mouth, e. g. due to dirty hands. The reference person is a child at play. It is assumed that children aged between 1 and 2 represent the most exposed group. (Bachmann et al. 2007) support this assumption and state that other literature on the subject agrees that children aged between 1 and 3 consume far more ground material than children aged between 4 and 8 due to their playing habits.

A-5.2 Estimate principles

An exposure period of 1 day is assumed, during which time the radionuclides decay. It can be assumed that after one day, the warning described in Section A-5.5 is heeded. In order to estimate the effective dose from a radionuclide without daughter nuclides (to be taken into account), the following formula can be used:

$$E_{g,Bo,r} = U_{Bo} \cdot g_{g,r,E} \cdot C_{Bo,r} \cdot \frac{1 - e^{-\lambda_r \cdot T_e}}{\lambda_r} \cdot T_{Sp} \cdot AF_{0,5,r} \cdot 1{,}000 \quad \text{(A-24)}$$

where

$E_{g,Bo,r}$ is the effective dose from ground consumption (ingestion) of radionuclide *r* in mSv,

U_{Bo} is the ground consumption rate in kg h^{-1}

$g_{g,r,E}$ is the dose coefficient (effective dose) for radionuclide *r* in Sv Bq^{-1},

$C_{Bo,r}(t)$ is the specific activity of radionuclide *r* in the ground in Bq kg^{-1} at time t,

T_e is the exposure period in d,

λ_r is the decay constant for radionuclide *r* in d^{-1},

T_{Sp} is the daily exposure in h d^{-1},

$AF_{0,5,r}$ is the concentration factor that describes the average ratio of specific activity of radionuclide *r* of the fine particle fraction and total sample (see below). It is dimensionless,

1,000 is the conversion factor from Sv to mSv.

The specific activity of the ground $C_{Bo,r}(t)$ can be estimated by dividing the ground contamination $B_r(t)$ (in Bq m^{-2}) by the depth of the ground layer d (in m) throughout which the activity has spread, and by the ground density ρ_{Bo}:

$$C_{Bo,r}(t) = \frac{B_r(t)}{d \cdot \rho_{Bo}}, \quad \text{(A-25)}$$

$$B_r(t) = B_r(0) \cdot e^{-\lambda_r \cdot t}. \quad \text{(A-26)}$$

An important parameter for the above estimate is the soil consumption rate U_{Bo}. In general, there is little data available from known investigations (Bachmann et al. 2007). In the cited document, a soil consumption rate of 500 mg d^{-1} is assumed for the group of children aged between 1 and 3. This value is based on data from the United States and is considered to be conservative.

A German investigation (Bothe 2004) states an average soil consumption rate of around 100 mg d^{-1} for children at play. This value is based on average daily outdoor playing time and is in line with other sources (cited in Bothe 2004) in terms of its magnitude.

The Calculation Guide Mining (BglBb) (BfS 2010) provides a soil consumption rate of 50 mg h^{-1} ($5 \cdot 10^{-5}$ kg h^{-1}) for children aged between 1 and 2, which is the highest value for a variety of age groups. BglBb also states 1,000 h a^{-1} (almost 3 hours per day) as the length of time spent in play areas.

A French document produced within the scope of the CODIRPA project assumes soil consumption rates of 30 mg d^{-1} to 100 mg d^{-1} (ASN 2010).

In any case, soil consumption is clearly linked to playing outdoors and is therefore dependent upon the time of year (season). Calculation methods to protect the ground (Bachmann et al. 2007) therefore assume an exposure on 240 days of the year.

Another important parameter in formula (A-25) is the thickness of the soil layer throughout which the activity has spread. The thinner the layer, the higher the specific activity. No empirical data could be found for this parameter. Over time, the contamination initially present on the surface will mix with the top layer of sand when children play there. Here it is assumed that the ingestion of contaminated sand takes place on the first day after contamination if the deposited activity is still on the surface.

The concentration factor $AF_{0,5,r}$ takes account of the fact that the specific activity of the fine particle fraction of the soil is higher than that of the total sample. It is assumed that mainly the fine particle fraction will be ingested. The concentration factor is dimensionless and, according to the Calculation Guide Mining (BglBb) (BfS 2010), $AF_{0,5,r} = 2$ applies to all radionuclides r.

The ingestion dose coefficients for the radionuclides of relevance here and which are needed to perform the calculation can be taken from (BMU 2001).

As stated in Annex A-1, the effective dose from soil consumption $E_{g,Bo}$ in mSv for parent-daughter radionuclide mixtures can be expressed as follows:

$$E_{g,Bo} = \frac{B_G(T_a)}{d \cdot \rho_{Bo}} \cdot p_1(T_a) \cdot e^{\lambda_1 \cdot T_a} \cdot U_{Bo} \cdot AF_{0,5} \cdot T_{sp} \cdot 1{,}000 \sum_{r=1}^{n} g_{g,r} \cdot \left(\int_0^{T_a+T_e} \frac{B_r(t)}{B_r^0} dt - \int_0^{T_a} \frac{B_r(t)}{B_r^0} dt \right). \quad \text{(A-27)}$$

The definitions provided above and in Annex A-1 apply.

A-5.3 Estimate

The following assumptions were made in order to estimate radiation exposure due to contamination:

Soil ingestion rate according to (Bachmann et al. 2007, BfS 2010):	U_{Bo} = 50 mg h^{-1}(= 5 E-5 kg h^{-1})
Daily outdoor playing time (in sand-pit):	T_{sp} = 2.7 h^{-1}
Exposure period:	T_e = 1 d
Sand density:	ρ_{Bo} = 1,800 kg $^{-3}$
Thickness of sand layer exhibiting activity:	D = 0.001 m
Ground contamination at the start of the exposure period:	$B_G(T_a)$ = 1 Bq m^{-2}.

The ingestion dose coefficients for the effective dose for the age group 1 to 2 years (BMU 2001) were used. Most of the assumptions are used in a proportional way (the sand layer thickness is used in an inversely proportional manner) to achieve the result.

Based on the above parameters, the ground area whose activity is incorporated by the child is approximately 1 cm^2.

There is no intervention level for the “issue a warning to the general public instructing them not to let children play outdoors” measure to be taken. A dose reference level of 1 mSv is stipulated in order to simplify the calculation.

The exposure pathway can be interrupted by relatively easy to implement measures (e. g. immediate closure of playgrounds, possibly by performing contamination measurements and by giving priority to decontamination by replacing the sand).

A-5.4 Results of calculations “Ingestion of contaminated soil constituents by small children”

Radionuclide	**Max. normed dose** in mSv relating to 1 Bq m^{-2}	**Operational intervention level of ground contamination** in Bq m^{-2} relating to 1 mSv effective dose on the 1st day
Beta emitters		
P-32	2.8E-09	3.5E+08
P-33	2.7E-10	3.7E+09
S-35	1.3E-10	7.6E+09
Ca-45	7.4E-10	1.3E+09
Ni-63	1.3E-10	7.8E+09
Sr-89	2.7E-09	3.7E+08
Sr-90#	7.1E-09	1.4E+08
Y-90	2.7E-09	3.7E+08
Pr-143	1.3E-09	7.7E+08
Pm-147	2.9E-10	3.5E+09
Er-169	4.1E-10	2.4E+09
Tm-170	1.5E-09	6.7E+08
Tl-204	1.3E-09	7.7E+08
Bi-210	1.4E-09	7.3E+08
Alpha emitters		
Po-210	1.3E-06	7.5E+05
Ra-223#	2.7E-08	3.7E+07
Ra-226#	9.0E-08	1.1E+07
Ac-225#	4.5E-09	2.2E+08
Ac-227#	8.1E-08	1.2E+07
Th-227#	2.5E-08	4.0E+07
Th-228#	2.4E-08	4.2E+07
Th-229#	4.4E-08	2.3E+07
U-234	2.0E-08	5.1E+07
U-235#	1.0E-08	9.9E+07
U-238#	7.4E-09	1.4E+08
Unat#	1.1E-08	9.5E+08
U5%#	1.6E-08	6.1E+08
Udep#	8.0E-09	1.2E+09
Pu-238	6.1E-08	1.6E+07
Pu-239	6.4E-08	1.6E+07
Pu-240	6.4E-08	1.6E+07
Am-241	5.6E-08	1.8E+07
Cm-242	1.2E-08	8.7E+07
Cm-244	4.4E-08	2.3E+07
Cf-252	7.8E-08	1.3E+07

By comparing the ground contaminations set out in this specific example with those provided in the preceding annexes, it can be seen that – depending on the radionuclide or radionuclide mixture – lower contaminations are sufficient to exceed the dose reference level of 1 mSv for this exposure pathway.

Based on this scenario, the lowest operational intervention level in this list is that of Po-210 which is 7.5 10^5 Bq m^{-2} per 1 mSv on the 1st day. Other ingestion scenarios are possible which could lead to even higher ingestion doses.

A-5.5 Warning against unintentional ingestion

In the event of a justified suspicion or after gaining knowledge of a contamination involving alpha or beta emitting radioactive material, precautionary measures should be imposed upon the general public. According to (IAEA 2013), such precautionary measures could include the following:

- No consumption of foodstuffs stored openly and therefore potentially contaminated
- Refrain from contact with outdoor objects
- Avoid contact with the mouth before washing hands
- Children should not be allowed to play outdoors
- Refrain from activities that generate a lot of dust.

In each case, such a warning should be issued very early on if there is good reason for doing so. At this point in time there is probably little information available about the kind and extent of contamination involved.

Warnings should contain the proviso that they may be rescinded or extended.

Even if no specific information about the present radionuclide/nuclide mixture is available at the time, attempts should be made to gain insights into the size of the area to be warned. The ground contamination at which measures to defend against immediate hazards become necessary is assumed as a reference level and then compared with the operational intervention levels for unintentional ingestion provided above. This, in turn, shows that for a number of radionuclides a large hazard area is not required. With a different set of radionuclides, the operational intervention level for the ingestion scenario is lower than the given reference level. This means that the area where warnings must be issues is larger than the area designated for immediate hazard defence. For some radionuclides, the difference is a factor of approximately 100.

With dry deposition, ground contaminations in various locations are approximately proportional to the dispersion factors χ for these locations. With wet deposition, the ratio of the total of fallout (F) and washout (W) factors for these locations are used:

$$\frac{B_1}{B_2} = \frac{\chi_1}{\chi_2} \quad \text{and} \quad \frac{B_1}{B_2} = \frac{F_1 + W_1}{F_2 + W_2} . \qquad \text{(A-28)}$$

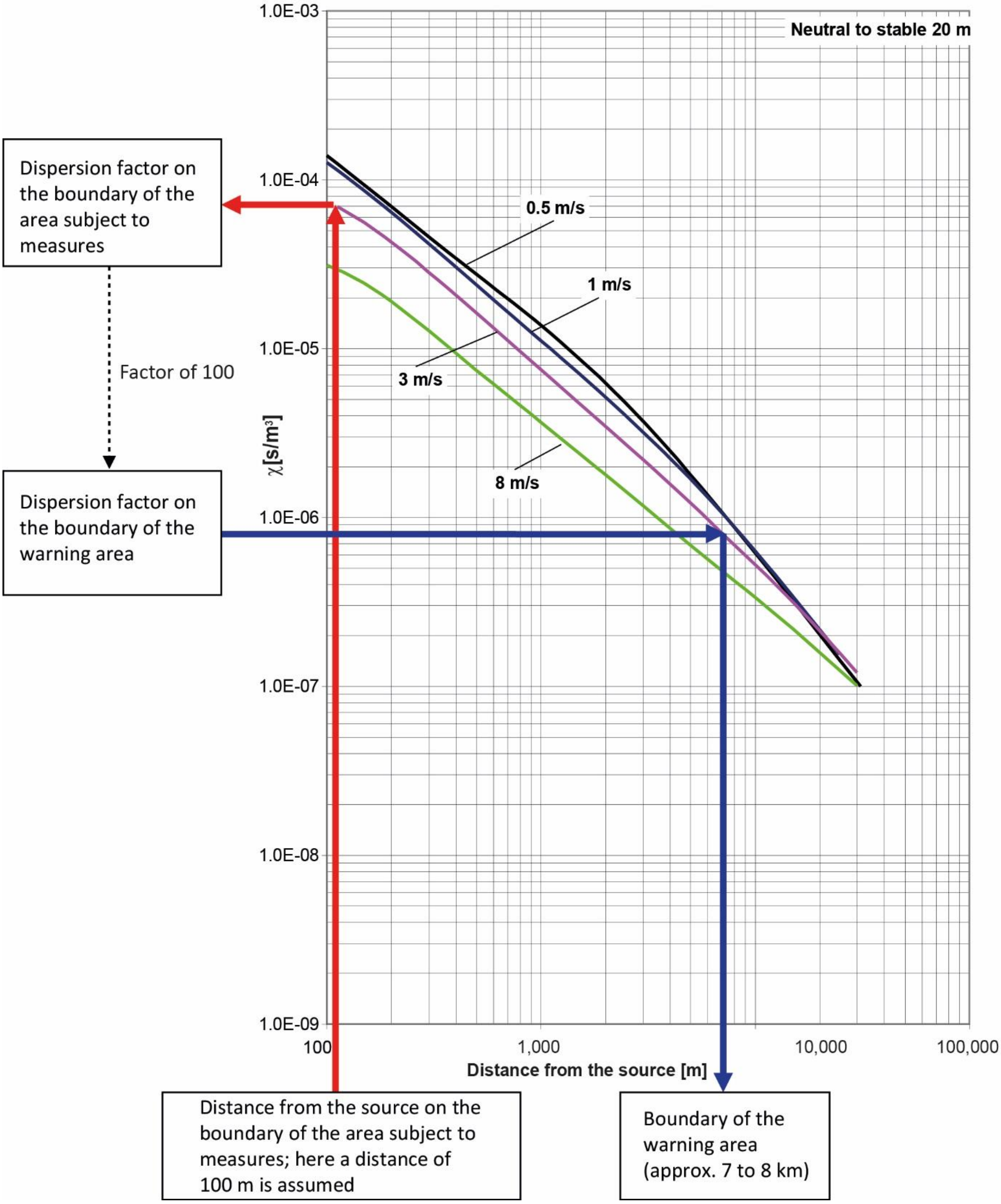

Fig. A-5.1: Estimating the hazard area using a graph to represent the dispersion factor (according to SSK 2002)

Figure A-5.1 demonstrates that there is a 100 times compensation at around 8 km for frequently occurring weather conditions (wind speed of 3 m s^{-1} at a height of 10 m). It is therefore suggested to issue an initial warning for an area of up to 8 km.

In order to account for wind direction fluctuations and horizontal diffusion, a sector of up to around 45 degrees should also be warned as a precautionary measure. Based on experience, the main wind direction fluctuations occur at low wind speeds and during stable and unstable turbulence periods in the atmosphere. The 45-degree angle compensates for these factors.

If a measurement of released activity, preferably close to the source, is available and the radionuclide or radionuclide mixture is known, the same method as the one provided in Figure A-5.1 can be used. To do so, the ratio of the result of the contamination measurement for the ingestion intervention level provided in Section A-5.5 has to be transferred to the ratio of dispersion factors by determining the dispersion factor at the measurement locations.

A corresponding method can be relatively easily applied using a dispersion program (e. g. LASAIR (Walter and Heinrich 2011)).

A-6 On the detectability of alpha emitting radionuclides and radionuclide mixtures by measuring the local gamma dose rate

Most of the individual alpha emitting nuclides considered here and all of the alpha emitting radionuclide mixtures taken into account here also emit gamma radiation which can, in principle, be detected using conventional local dose rate measuring devices. For this reason, an investigation was performed to see whether the gamma radiation can be used to determine the boundaries of the affected area.

To do this, the gamma dose rates were calculated and the assumption made that the dose rate for penetrating radiation is an approximate value of the effective dose for a person who is outdoors in the location under consideration. To this end, the (initial) dose rates *DL* in µSv h^{-1} upon commencement of the exposure in this scenario were calculated for the radionuclides and radionuclide mixtures under consideration here by using the following formula:

$$DL = B_G \cdot \sum_r p_r \cdot g_{Bo,r,E} \cdot 3{,}600 \cdot 10^6 \qquad \text{(A-29)}$$

where

r is the index for all of the radionuclides of the radionuclide mixture under consideration; with individual nuclides: $r=1$

B_G is the total ground contamination $= \sum_r B_r$ in Bq m^{-2}

B_r is the ground contamination from radionuclide r in Bq m^{-2}

p_r is the proportion of radionuclide r of the total ground contamination B_G from all radionuclides r of the radionuclide mixture; with individual nuclides this is set to 1 (dimensionless)

$g_{Bo,r,E}$ is the dose-rate coefficient (effective dose) for external gamma radiation for the ground-deposited radionuclide r in Sv m² Bq^{-1}s^{-1}, a corresponding table for adults is provided in (BMU 2001)

3,600 is the conversion from s to h

10^6 is the conversion from Sv to µSv.

In order to derive B_G, the ground contamination set out in Table 3 for which the intervention level of 10 mSv (effective dose) in 7 days is reached by remaining outdoors was used together with ground contamination of 1 MBq m^{-2}. This final stipulation is based on the IAEA intervention level for alpha emitting radionuclides (see Section 7.1).

The results of these calculations are set out in the table below. They show that despite a low local dose rate, there may still be significant contamination involving alpha emitters. It is also possible that the values of the measured local dose rates do not differ or only slightly differ from the background radiation (background) which can vary significantly between 0.06 µSv h^{-1} and 0.4 µSv h^{-1} in urban areas depending on the surface material (e. g. concrete, asphalt, granite).

Nuclide	Initial gamma dose rate in µSv h^{-1} at the intervention level	Initial gamma dose rate in µSv h^{-1} at 1 MBq m^{-2} level	Initial gamma dose rate ≥ 0.1 µSv h^{-1} at the intervention level	Initial gamma dose rate ≥ 0.1 µSv h^{-1} at 1 MBq m^{-2} level	Initial gamma dose rate ≥ 0.3 µSv h^{-1} at 1 MBq m^{-2} level
Ra-223#	4.3E+00	1.3E-01	+	+	
Ra-226#	1.3E+01	4.1E-01	+	+	+
Ac-225#	6.4E+00	1.3E-01	+	+	
Ac-227#	1.2E-01	1.4E-01	+	+	
Th-227#	3.5E+00	1.6E-01	+	+	
Th-228#	8.0E+00	6.8E-01	+	+	+
Th-229#	2.9E-00	1.3E-01	+	+	
U-nat#	6.5E-01	3.5E-02	+		
U-5%#	3.8E-01	2.5E-01	+	+	
U-dep#	8.5E-01	3.0E-02	+		
Pu-238	2.9E-03	2.5E-03			
Pu-239	1.2E-03	1.2E-03			
Am-241	1.1E-01	8.1E-02	+		
Cm-242	6.0E-02	2.7E-03			
Cm-244	5.6E-03	2.5E-03			
Cf-252	1.3E-02	2.0E-03			

A-7 Information about contamination measuring devices

In order to measure surface contaminations, indicative measurements can be taken using mobile alpha/beta sensitive contamination measuring devices with gas-filled detectors or thin-layer plastic scintillators. Readings from contamination measuring devices are generally shown in impulses per unit of time. Measuring device manufacturers provide calibration factors to convert impulses per unit of time to activity per area in Bq cm^{-2} for a number of the radionuclides considered here as well as common decay series such as U-nat and gross alpha or gross beta activity. These calibration factors are generally determined using test emitters. If these calibration factors are not available, a calibration factor for a suitable substitute nuclide such as Am-241 can be used for alpha emitters or Cl-36 for beta emitters. The deviation for beta emitters with a maximum beta energy of more than 0.1 MeV is less than a factor of 3, while the deviation for the alpha emitters under consideration here is less than a factor of 5. In theory, calibration factors can be mathematically derived for all other radionuclides and decay series (Heinzelmann and Schnepel 1992), including exotic radionuclides and decay series for which there are no test emitters available.

Table A-7.1 provides examples of calibration factors for commercial contamination measuring devices provided by their manufacturers as well as the count rates to be expected based on the operational intervention levels used here. As these devices were developed to detect low levels of contamination, the measuring ranges may be exceeded for certain intervention levels. The SSK points out that the measuring devices available on the market are not able to reliably quantify contaminations at the intervention levels proposed here. Measuring probes with small sensor windows and low sensitivity can be used to counter this effect somewhat.

Particularly with alpha radiation, the count rate provided by contamination measuring devices is highly dependent upon the distance from the contaminated surface, the surface properties, and distribution of the activity on the area, meaning that the results of alpha measurements performed during deployments are subject to major uncertainties.

It should also be noted that the calibration factors for radionuclides with decay series provided by device manufacturers generally refer to the parent nuclide’s activity. The operational intervention levels used here, however, refer to the total activity from parent and daughter nuclides at the time of release assumed in the calculations. This means, for example, that the intervention level for the decay series Sr-90# is reached if the parent activity of Sr-90 reaches half of the intervention level because the daughter nuclide Y-90 also contributes the same number of beta decays.

Table A-7.1: Examples of calibration factors for commercial contamination measuring devices provided by their manufacturers as well as the count rates to be expected based on the operational intervention levels (Automess 2004, Berthold 2012, SEA 2014)

	Berthold LB124 SCINT Detector surface 170 cm²		**Automess 6150AD-k** Detector surface 170 cm²		**CoMo 170** Detector surface 170 cm²		**Automess 6150AD-17**[a] Detector surface 6.2 cm²	
	Operating mode: Alpha	Operating mode: Beta/gamma	Operating mode: Alpha	Operating mode: Alpha/beta/gamma	Operating mode: Alpha	Operating mode: Beta/gamma	Operating mode: Alpha/beta/gamma	
Calibration factors in s Bq cm^{-2}	gross alpha 0.059	gross beta 0.017	Am-241 0.074	Cl-36 0.026	Am-241 0.029	Cl-36 0.014	Am-241 1.3	Cl-36 0.7
Device-specific maximum count rate in imp sec^{-1}	approx. 5,000	approx. 50,000	approx. 20,000	approx. 20,000 [b]	approx. 5,000	approx. 50,000	approx. 10,000	approx. 10,000
Maximum detectable area contamination in Bq cm^{-2}	approx. 300	approx. 850	approx. 1,500	approx. 500	approx. 150	approx. 700	approx. 13,000	approx. 7,000
Examples of net count rates in imp sec^{-1} for intervention levels for initial measures as per Section 7.1								
Beta emitters: 10,000 Bq cm^{-2}	-	>MB [c]	-	>MB	-	>MB	-	>MB
Alpha emitters: 100 Bq cm^{-2}	1,700	-	1,400	-	3,400	-	77	-
for nuclide-specific intervention levels as per Section 7.1								
P-32 23,000 Bq cm^{-2}	-	>MB	-	>MB	-	>MB	-	>MB
Po-210: 3,000 Bq cm^{-2}	>MB	-	>MB		>MB	-	2,300	4,300
for intervention levels for skin contamination as per Section 7.2								
1,000 Bq cm^{-2}	>MB	-	14,000	-	>MB	-	770	-
100 Bq cm^{-2}	-	5,900	-	3,800	-	7,100	-	140
1 Bq cm^{-2}	17	-	14	-	34	-	1	-

a Geiger-Müller tube without adjustable discriminator threshold to distinguish between alpha and beta/gamma radiation.
b Non-linear range up to approx. 80000 Imp sec^{-1}
c > MB: Measurement range exceeded

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