Strahlenschutzkommission

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Determining radiation exposure

Recommendation by the
German Commission on Radiological Protection

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Ermittlung der Strahlenexposition

Empfehlung der Strahlenschutzkommission

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1 Introduction

In many cases, radioecology is used to describe the effects of radionuclide emissions and releases on humans and the environment, and to quantify radiation exposure by means of modelling. Radioecological methods must be used in all cases where radiation exposure cannot be measured directly. This includes the reconstruction of past exposure, the determination of current exposure, and the prediction of future or potential exposure. Radioecological modelling may involve individuals, groups of employees, members of the public, entire populations, or reference persons. The objectives of radioecological exposure assessments are as varied as their potential methodical approaches.

A fundamental problem that arises in connection with methodical approaches is the extent to which conservatism or realism is used in radioecological exposure assessments. European Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation (Euratom Basic Safety Standards) (EC 1996) requires occupational radiation exposure to be determined as realistically as possible for the population as a whole and for reference groups of the population, but without defining how this should take place in practice. By way of contrast and as a precautionary measure, licencing procedures in Germany involving the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) (BMU 2012a) are subject to extremely conservative estimates in terms of potential radiation exposure.

This apparent contrast repeatedly leads to controversial discussions if the fact is overlooked that different objectives require different methodical approaches. The question of what level of conservatism or realism is necessary for which objective remains largely unanswered in German legislation.

To date, the documentation related to this situation has used terms such as determination, assessment and estimation to indicate the same thing. The Euratom Basic Safety Standards, for example, uses estimates, as can be seen here: "*The competent authorities shall: (a) ensure that dose estimates from practices referred to in Article 44 are made as realistic as possible for the population as a whole and for reference groups of the population in all places where such groups may occur; (b)...*".

The International Commission on Radiological Protection (ICRP) uses both assessment and estimates in recommendation 103 (ICRP 2007). An example of this can be seen in Chapter 6.6.5 Compliance with the intended standard of protection: *"(320) The measurement or assessment of radiation doses is fundamental to the practice of radiological protection. Neither the equivalent dose in an organ nor the effective dose can be measured directly. Values of these quantities must be inferred with the aid of models, usually involving environmental, metabolic, and dosimetric components. Ideally, these models and the values chosen for their parameters should be realistic, so that the results they give can be described as 'best estimates'. Where practicable, estimates and discussion should be made of the uncertainties inherent in these results (see Section 4.4)*". The ICRP included this sentence word for word in Section 264 of Chapter 7.5 *Assessment of doses* of its recommendations in publication 60 (1991).

For the purpose of clarity and consistency, the SSK has elected to use the term estimate within the sense of a best estimate as used in the Euratom Basic Safety Standards.

Another problem that arises is the fact that radiation exposure is highly variable within a population and depends on a number of parameters that must be considered as random variables under natural environmental conditions. Consequently, radiation exposure of the general population is a random quantity as well. As a result, radiation exposure among a population or other group will exhibit distributions that retrospectively represent the actual differences in individual exposure, while also indicating the anticipated distributions of future or potential exposure.

In view of the stochastic character of individual radiation exposure, the quantities to be used in radioecological exposure estimations for characterising exposure still remain unclarified in Germany. The options available range from stipulating simple point estimates through to the description of complete distributions, which therefore requires further clarification.

A third problem is that the term “realistic” has not been clearly defined. Everyday language offers differing interpretations of the word. Without entering into a general semantic discussion, the SSK discriminates between realistic determination, i.e. best estimate[1] (“realistische Ermittlung”), as set out in the Euratom Basic Safety Standards against a conservative estimate (“Abschätzung”). A best estimate should neither deliberately over- or underestimate the true value of a dose quantity, i.e. it should be distortion-free and unbiased.

Based on this understanding of the term realism, one aspect needs to be differentiated that comes up time and again when discussing dose estimates: the uncertainty of the estimate. Here, realism is often linked to a given relative uncertainty. The SSK considers this to be inappropriate as a highly uncertain estimate may also be realistic. On the other hand, an estimate with little uncertainty may in fact be unrealistic. Realistic estimates of radiation exposure and the accompanying uncertainty analyses are different yet complementary tasks both of which need to be performed.

The amount of work required to assess radiation exposure realistically and avoid unacceptably high uncertainties is, on the one hand, scientifically dependent on the options and limitations of radioecology. On the other hand, it depends on the value that society places on estimating radiation exposure for a certain objective, and what expense of resources is socially justifiable. To date, it has not been possible to address both these points exhaustively.

In its correspondence to the SSK on 6 November 2006, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) asked the SSK for advice on how to realistically estimate radiation exposure.

In reference to the requirement to ensure that dose estimates from practices referred to in Article 44 are as realistic as possible for the population as a whole, the BMU would like to see the drafting of a recommendation that addresses the following aspects:

– The identification and determination of situations where a realistic calculation of radiation exposure would be necessary or useful,

– The stipulation of models, model parameters and model quantities to be used realistically with identified situations.

At its closed meeting held in Eltville am Rhein on the 25th and 36th of November 2003, the SSK’s Radioecology Committee conducted an expert review of the requirements and options for realistically estimating radiation exposure (SSK 2005a). On the basis of this meeting and other discussions, the SSK drew up this recommendation containing requirements with regard to estimating radiation exposure for the various objectives and the methods to be applied in each case.

[1] The best estimate and its associated standard uncertainty are defined according the GUM (JCGM 2008a) (clause 4.1.6) and GUM Supplement 1 (JCGM 2008b) (clause 5.6.2) as expectation and standard deviation, respectively, of the probability density function (PDF) of a measurand.

2 Recommendation

This recommendation investigates realism requirements in terms of estimating radiation exposure on the basis of radioecological modelling. In general, this recommendation can be applied to any exposure situation in which exposure scenarios can be derived from FEPs (features, events and processes). An exposure situation scenario involves the natural and technical characteristics of the exposure situation as well as a set of processes and events that can influence human exposure to radiation and determine exposure scenarios.

The fundamental task of radioecology is to use models to estimate the dose to reference persons or real people at any given location during an exposure situation. The respective output quantity must be clearly defined in order to avoid misinterpretations when comparing different doses. It is of little importance whether the output quantity value of an exposure estimate is used for comparison with a limit, constraint or reference level. It is also of little importance whether it is merely used as an indicator quantity, as is the case with long-term safety assessments, or for scientific analyses.

A clear definition of the output quantity impacts both the stipulation of the dose variable and the reference person, including their characteristics. It is therefore important to determine whether the person involved is a real person or reference person as defined in ICRP 23 (ICRP 1975), a person with average exposure within a population, or a person representative of more highly exposed parts of a population.

For the purpose of the latter, i.e. those (persons) in low-probability exposure situations, the ICRP introduced the representative reference person concept (ICRP 2006). The dose to the representative person is equivalent to the average dose to persons in the “critical group” in past ICRP recommendations, and therefore replaces it. The ICRP considers it sufficient to use three age categories for the representative person: infant (1 year old, representing 0-5 year olds), child (10 years old, representing 6-15 year olds) and adult (representing 16-70 year olds).

The SSK attaches particular importance to distinguishing between the reference person described in ICRP 23 and the representative person defined in ICRP 101 (ICRP 2006) when drafting legislation. It recommends the inclusion of the representative reference person in German legislation to refer to the more highly exposed persons of a population. This recommendation therefore distinguishes between a reference person and a representative person.

No matter how it is specified, the dose to a person is based on the source characteristics and the link between resulting concentrations of radioactive material in the environment and the person’s lifestyle and consumption habits. This can and should be estimated as realistically as possible.

Within the context of this recommendation, realistic radiation exposure estimation means to provide as accurate an estimate of the true value of the measurand as possible based on the information available, and to quantify the estimate’s level of uncertainty[2]. This involves two aspects. Firstly, the avoidance of overestimations (conservatism) and underestimations. Secondly, the level of uncertainty should be kept as low as possible taking account of all sources

[2] With varying levels of conservatism, conservative dose estimates may be used as proof of adherence to limits or constraints, but they do not constitute best estimates.

of uncertainty. Minimization of the over- or underestimation of the true exposure as well as smaller uncertainties allow for more realistic estimates of radiation exposure.

Setting-up the model of evaluation[3] is the most difficult part of solving the task, both in terms of general metrology and for estimating dose exposure. This recommendation assumes there is a meaningful model in place that is in line with the state of the art in science and technology. Comparable situations addressing different aspects should be described by the same models. Where used, simplified models should be undistorted and unbiased and the approximations sufficient. Overarching models, i.e. models involving conservative overestimates, are sufficient in order to answer certain questions, but the SSK does not consider them suitable as realistic dose estimates.

Known exposure situations should be used to make sure the model reflects reality in as far as possible. A model that fails to describe natural circumstances or past experiences is not suitable for producing realistic radiation exposure estimates.

In accordance with a recommendation published by the World Health Organization (WHO) in 2008 (WHO 2008), the SSK considers it necessary to stipulate the level of uncertainty attributed to the output which, above all, reflects the variability of the input quantities. The need to quantify uncertainties when estimating radiation exposure is based on ICRP 103 (ICRP 2007) and the optimisation approach used there. Optimisation is generally not possible without a realistic dose exposure estimate. The ICRP 103 approach depends on the probabilistic method, i.e. the estimation of probability density functions (PDFs) of exposures for optimisation to be possible. This is because during optimisation particular attention is paid to the PDF quantiles that display dose exposure values above the reference values.

When interpreting the determined PDF, it must be noted that these retrospectively show the actual differences between the individual exposures, i.e. the frequency distributions of the exposures. From a prospective viewpoint, they describe both the distributions of future or potential exposures and the exposure probability of an undefined individual from among the considered population.

Uncertainties should ideally be portrayed by PDFs rather than by stipulating best estimates and standard uncertainties. The PDFs of the output quantities have to be determined in order to estimate output quantity quantiles. Deterministic calculations with quantiles do not produce quantiles but are highly distorted. Sensitivity analyses within the scope of uncertainty analyses enable the identification of critical parameters for which detailed information must be acquired.

The SSK therefore recommends the PDF be used wherever possible in order to take account of uncertainties. This requires an information or data basis in order to be able to derive the PDF. The SSK recommends to collect the data required to derive a reasonable PDF and the underlying primary studies at the Federal Office for Radiation Protection (BfS) in order to determine radiological parameters such as transfer factors and consumption rates, and then make such data available to the general public.

In cases where the information or data available does not allow for the derivation of a reasonable PDF, other methods that account for existing uncertainties such as the definition of bands (Barthel and Thierfeldt, 2012), the 2D Monte Carlo simulation, and p-Box may need to be used.

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[3] Based on the International Vocabulary of Metrology — Basic and General Concepts and Associated Terms (VIM) (JGCM 2008c), the model of evaluation is the sum of the mathematical relations of all quantities used to estimate the output quantity value.

This recommendation assumes that the present information and data basis allow a reasonable PDF to be derived for radiological parameters.

Radioecological dose estimates for a certain source have to be based on model calculations and/or measurements involving relevant environmental media. Figure 2.1 illustrates the complex pathways that radionuclides take when passing through the environment from a source to humans. To simplify the example, skin dose and the potential exposure pathway “absorption of radionuclides by the skin” are not included.

Figure 2.1 provides examples of frequently occurring exposure situations. It does not represent every exposure situation or scenario that can be described by FEPs. Models used to derive clearances, including scenarios such as “people who work on a contaminated machine” or “in a contaminated laboratory”, “truck drivers with disposal clearance” or “landfill workers with disposal clearance”, use other models. Nevertheless, the method described below can still be used in these cases.

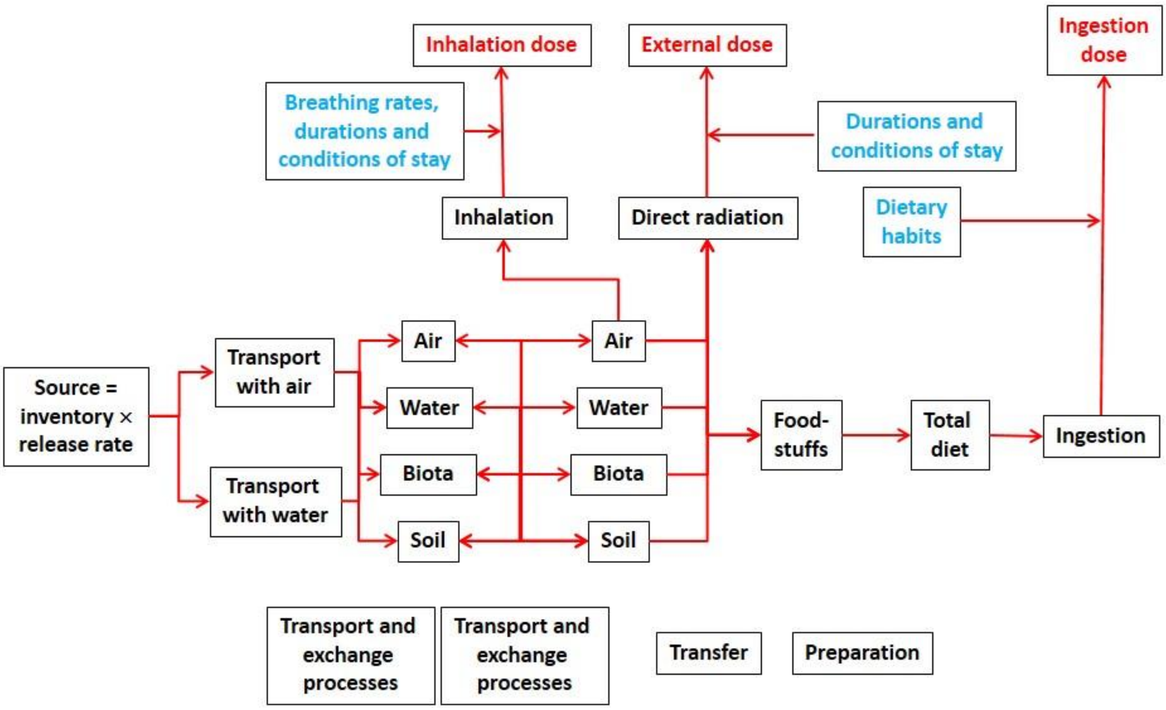

Fig. 2.1: Examples of pathways radionuclides take from a source to humans.

The complexity of the models/model structures and the realism of the modelling depend both on the information available about the source and radionuclides in the various environmental media, and on the knowledge of the situations that can lead to human exposure.

Table 2.1 contains five categories, I0 – I4, which show the information available for each case in terms of estimating radiation exposure. Modelling depending on the adequacy of the information allows for increasingly realistic dose estimates from category I0 to category I4.

Table 2.1: Categorisation of dose estimates based on available information (information categorisation).

Category	Available information
I0	From an overarching hypothetical source term
I1	From a hypothetical source term (best estimate based on predictions)
I2	From an actual source term (best estimate based on measured data)
I3	From the measured ambient dose rate and activity concentrations in foodstuffs modelled from data measured for the air, soil and water
I4	From measured activity concentrations in the air, soil, water, foodstuffs, ambient dose rate as well as dosimeters, whole-body measurements, bioassay, etc.

When estimating exposure, the scenarios and exposure paths, radioecological model parameters and human parameters resulting from the FEPs are used as input quantities to characterise the exposure situation. The information available about the exposure situation also determines how realistic the modelling/exposure estimate is. Table 2.2 shows a system with 4 levels for FEPs, scenarios and exposure paths, radioecological model parameters and human parameters. These levels are designated below as situation categories. The input quantity values range from overarching and impossible (S0), potential and generic (S1), case-specific and real (S2), through to case-specific and individual data (S3). Dose estimates are most realistic for S3 and least realistic for S0. The transition from S0 to S1 serves the removal of overestimates (conservatisms), while the transition from S1 to S3 sees the removal of uncertainties.

Table 2.2: Categorisation of FEPs, scenarios and exposure pathways, radioecological model parameters and human parameters (situation categorisation).

	Situation category (Levels of FEPs, scenarios and exposure pathways, model parameters, human parameters)			
	S0	**S1**	**S2**	**S3**
FEPs, scenarios and exposure pathways	Overarching (also impossible); e.g. equilibrium condition (50 a), ubiquity, implausible consumption quantities	Only realistically and legally feasible; generic; disequilibria	Real case-specific; disequilibria	Real case-specific and legally feasible; individual data of a cohort; disequilibria
Radioecological model parameters*	Generic 95th percentile	Generic data	Case-specific data	Case-specific data
Dietary habits	Generic data, either overarching or 95th percentile	Generic data	Case-specific data	Individual data
Durations of stay	Duration of stay	Generic data	Case-specific data	Individual data
Percentage of locally produced foodstuffs	100%	Generic data	Case-specific data	Individual data

* e.g. K_d levels, transfer factors, solubilities, etc.

The available radiation source information determines the information category. FEPs, scenarios and exposure paths, radioecological model parameters and human parameters determine the situation category. The level of modelling realism is determined by combining an information category with a situation category. The realism of dose estimations increases with information category (I1 < I2 < I3 < I4) and situation category (S0 < S1 < S2 < S3). Table 2.3 shows the level of realism by means of colour coding where red means unrealistic and green means realistic. The Euratom Basic Safety Standards demand estimation of radiation exposure from practices to be as realistic as possible. In Table 2.3, this means striving to end up in the bottom right-hand corner with a reasonable amount of work.

Table 2.3: Categorisation of potential dose estimates.

Situation category / Information category	**S0** Overarching (also impossible); e.g. equilibrium condition (50 a), ubiquity, implausible consumption quantities	**S1** Only realistically and legally feasible; generic; disequilibria	**S2** real case-specific and legally feasible; disequilibria	**S3** Real case-specific and legally feasible; individual data of a cohort; disequilibria
I0 From a overarching hypothetical source term				
I1 From a hypothetical source				
I2 From an actual source				
I3 Data for the soil, air, ambient dose rate, and water				
I4 Data for the soil, air, water, foodstuffs, ambient dose rate as well as dosimeter, whole-body measurement, bioassay, etc.				

Given the classification of exposure situations pursuant to ICRP 103 into planned, existing or emergency exposure situations, and taking account of the fact that retrospective and prospective dose estimates will always have varying levels of information available, the SSK recommends performing radioecological dose estimations based on the scheme set out in Table 2.4.

Table 2.4:SSK recommendation for assigning application scopes to dose estimate categories.

Situation category / Information category	**S0** Overarching (also impossible); e.g. equilibrium condition (50 a), ubiquity, implausible consumption quantities	**S1** Only realistically and legally feasible; generic; disequilibria	**S2** Real case-specific and legally feasible; disequilibria	**S3** Real case-specific and legally feasible; individual data of a cohort; disequilibria
I0 From a overarching hypothetical source term	Prospectively in planned situations in licencing procedures involving the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV)			
I1 From a hypothetical source		Prospectively in emergency exposure situations and other* planned exposure situations	Prospectively in other* planned exposure situations	
I2 From an actual source		Retrospectively and prospectively in planned, existing and emergency exposure situations	Retrospectively and prospectively in planned, existing and emergency exposure situations	
I3 Data for the soil, air, ambient dose rate, and water		Retrospectively and prospectively in existing and emergency exposure situations	Retrospectively and prospectively in existing and emergency exposure situations	Retrospectively in existing and emergency exposure situations
I4 Data for the soil, air, water, foodstuffs, ambient dose rate as well as dosimeter, whole-body measurement, bioassay, etc.		Retrospectively and prospectively in existing and emergency exposure situations	Retrospectively and prospectively in existing and emergency exposure situations	Retrospectively and prospectively for cohorts in existing and emergency exposure situations

* Exposure situations not subject to authorisation as stipulated in § 47 of the Radiation Protection Ordinance (StrlSchV).

While the available source information determines the information category, various options (Table 2.5) are available when determining the situation category with the sub-aspects FEPs, scenarios and exposure pathways, radioecological model parameters and human parameters which, in turn, determine the amount of work required to estimate the input quantity values: Work (S1) < Work (S2) < Work (S3).

The SSK considers situation category S0 to only be appropriate in the case of the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) and the basis of estimation for incidences relating to § 50 StrlSchV. In all other exposure situations, S1 and, where possible, S2 should be used. S3 should be reserved for investigating cohorts involving critical groups existing in reality.

Table 2.5: SSK recommendation for realistic radiation exposure estimations in various exposure situations. The arrows indicate that a tiered approach may be of use in such cases.

	Prospective		**Retrospective**	
Planned exposure situations, licencing procedures involving the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV)	I0	S0	I2	S1 → S2
Other planned exposure situations; e.g. final nuclear waste repositories and contaminated sites	I1	S1 → S2	I2 → I4	S1 → S2
Emergency exposure situations	I1 → I4	S1 → S2	I3 → I4	S1 → S3
Existing exposure situations	I2 → I4	S1 → S2	I3 → I4	S1 → S3

One particular problem arises when estimating radiation exposure for situations in the distant future onto which current conditions cannot be transposed. This is the case, for example, with final nuclear waste repositories and contaminated sites. Here, potential radiation exposure cannot be realistically estimated because it is not possible to reliably predict exposure situations in the distant future. The potential radiation exposure estimates for long-term final nuclear waste repository and contaminated site assessments only constitute indicator values within the scope of long-term safety considerations. The uncertainty of this consideration can be mapped by varying the possible FEPs and exposure scenarios. Modelling for each individual FEP and scenario should be carried out as realistically as possible in order to compare the potential radiation exposures resulting from the various FEPs and exposure scenarios with the aim of optimising the planned measures.

Table 2.6 summarises the SSK's recommendation for various different application scopes. The information categories I*i* and situation categories S*j* are recommended based on the respective application scope. The recommended requirements in terms of quantifying uncertainties are indicated by "u(D)", i.e. standard uncertainties according to the GUM[4] (JCGM 2008a), or PDF, i.e. probability density functions or probability functions according to GUM Supplement 1 (JCGM 2008b).

As long as the methods used do not lead to overestimation or underestimation of radiation exposure, the SSK considers a tiered dose estimation approach to be sufficient in terms of meeting the Euratom Basic Safety Standards requirement. The various tiers may be based on the level of information available, meaning that a varying amount of information-gathering work may be required. The goal is to make estimates "as realistic as possible". In Table 2.3 this means striving to end up in the bottom right-hand corner with a reasonable amount of work.

The SSK therefore recommends that the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) should commission the work required to collect and provide the required data.

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4 **G**uide to the Expression of **U**ncertainty in **M**easurement

Table 2.6: SSK proposal for the various application scopes of dose estimations with recommendations from information categories I*i and situation categories* S*j including the uncertainties u(D) or PDF.*

	Application scopes	ICRP [a)]	I*i*; S*j*; u(D) or PDF	Purpose
I	**Information**			
I.1	**Natural radiation exposure**	EX	I3 → I4; S1; PDF	Parliamentary report
I.2	**Nuclear weapons testing**	EX	I3 → I4; S1; u(D)	Parliamentary report
I.3	**Chernobyl**	EX	I3 → I4; S1; PDF	Parliamentary report
I.4	**Nuclear technology, technology, research, medicine (for reporting purposes)**			
I.4-1	Radiation exposure among reference groups or members of the general public resulting from practices during normal operation	P	I2; S1 → S2; u(D) or PDF	EU Art. 45 parliamentary report
I.4-2	Radiation exposure among reference groups or members of the general public resulting from practices after incidents and accidents	EX	I2 → I4; S1 → S2 ; PDF	EU Art. 45 parliamentary report
I.5	**Epidemiological research**			
I.5-1	Epidemiological research; cohort and case-control studies	EX, EM	I4; S3; PDF	Science
I.5-2	Epidemiological research; ecological studies	EX	I4; S1 → S2, PDF	Science
II	**Limitation of doses by limit, constraint, reference and indicator values: Planning and monitoring**			
II.1	**Construction and operation of nuclear plants and facilities subject to authorisation as stipulated in § 47 of the Radiation Protection Ordinance (StrlSchV)**			
II.1-1	Licence - normal operation	P	I0; S0 (S1 for radioecological model parameters), none	§§ 13, 46 and 47 of the Radiation Protection Ordinance (StrlSchV)
II.1-2	Licence - design basis accident	P	I0; S0 (S1 for radioecological model parameters), none	§ 49 of the Radiation Protection Ordinance (StrlSchV)
II.1-3	Monitoring - normal operation	EX	I2; S1 → S2; none	Licencing conditions
II.2	**Emergency management**			General: §§ 51 to 58 of the Radiation Protection Ordinance (StrlSchV)
II.2-1	Stipulation of protective measures - short-term - prospective (based on forecasts)	EM	I1 → I2; S1 → S2 ; none	
II.2-2	Stipulation of protective measures - short-term - retrospective (based on activity measuring values)	EM	I3 → I4; S1 → S2; none	
II.2-3	Remediation	EX	I3 → I4; S1 → S2; PDF	
II.2-4	Stipulation of protective measures - long-term (suspension of use constraints, resettlement)	EM, EX	I3 → I4; S1 → S2; PDF	
II.2-5	Rescue operations - workers	EM	I1 → I3; S1 (→ S2); u(D) or PDF	§ 59 of the Radiation Protection Ordinance (StrlSchV)
II.3	**Clearance**			

	Application scopes	ICRP a)	I*i*; S*j*; u(D) or PDF	Purpose
II.3-1	Derivation of clearance values	P	I0; S1; PDF	§ 29 of the Radiation Protection Ordinance (StrlSchV)
II.3-2	Clearance on an individual basis	P	I1 → I2 b); S1 – S2; PDF	§ 29 of the Radiation Protection Ordinance (StrlSchV)
II.4	**Long-term safety analysis at final nuclear waste repositories**			
II.4-2	State of discussion for forecasts over foreseeable periods of time	P	I1; S1 → S2; PDF	ESK/SSK + ICRP
II.4-3	State of discussion for long-term assessments c)	P	I1; S1; PDF	
II.5	**Contaminated sites**			
II.5-1	Workers	P, EX	I3 → 4; S1 → S2; u(D) or PDF	§ 95 et seq. of the Radiation Protection Ordinance (StrlSchV)
II.5-2	Members of the general public	P, EX	I3 → I4; S1 → S2; u(D) or PDF	Calculation Guide Mining (BglBb)
II.5-3	Derivation of trigger or action values	EX	I0; S1 (S1 → S2 for radioecological model parameters); u(D) or PDF	*(does not exist yet)*
II.5-4	Individual case / current situation	EX	I2 → I4; S1 → S2; u(D)	
II.5-5	Individual case / during remediation	EX	I3 → I4; S1 → S2; PDF	
II.5-6	Individual case / future (with/without remediation)	EX	I1 → I3; S1; PDF	
II.6	**Standard**			
II.6-1	Workers	EX, P	I1 (hypothetical source term), I2 (actual source term); S2; u(D) or PDF	§§ 95 and 96 of the Radiation Protection Ordinance (StrlSchV)
II.6-2	Members of the general public	P	I1 → I2; S1 → S2; PDF	§§ 97, 98, 101, 102 of the Radiation Protection Ordinance (StrlSchV)

a) This column characterises exposure situations based on ICRP 103:
P: planned exposure situations, EX: existing exposure situations, EM: Emergency exposure situations.

b) In individual cases of clearance of areas up to I4

c) The potential radiation exposure estimates for long-term final nuclear waste repository and contaminated site assessments only constitute indicator values within the scope of long-term safety assessment considerations.

"u(D)": Uncertainties based on GUM (JCGM 2008a)

PDF: Uncertainties based on GUM Supplement 1 (JCGM 2008b)

The SSK's scientific foundation that forms part of this recommendation illustrates examples of the stipulations for various exposure situations as shown in Table 2.7. The table can be used as a template to accurately describe a problem, define the output quantity/quantities, provide clarity regarding the information category, characterise the main parameters, and stipulate the scope and method for dealing with uncertainties.

Table 2.7: Template for stipulating the output quantities to be determined as well as the categories and levels used for radioecological dose estimations.

Exposure situation, application, purpose:	**…**
Output quantity and values to be calculated	
Exposure modelling (I0 – I4)	
Scenarios and exposure pathways (S0 – S3)	
Radioecological model parameters (S0 – S3)	
Dietary habits (S0 – S3)	
Durations of stay (S0 – S3)	
Percentage of locally produced foodstuffs (S0 – S3)	
Uncertainties: (GUM, GUM Supplement 1)	

3 Scientific foundation

3.1 Introduction

At a closed meeting in 2003, the SSK's Radioecology Committee conducted an expert review of the requirements and options for realistically estimating radiation exposure (SSK 2005a). At the end of 2006, the SSK was commissioned to advise on realistic dose estimations. Based on this closed meeting and other in-depth discussions, the SSK drew up this recommendation containing requirements with regard to estimating radiation exposure for the various objectives and the methods to be applied in each case.

In order to handle this consulting mandate, the SSK used current legislation as a basis for looking into the various application scopes for which dose estimates are required. This in turn required clarification of the various terms used such as best estimate and conservative estimate. For the purpose of this recommendation, the SSK limits its considerations to (dose) estimates (see Section 3.3).

The SSK performed a critical analysis of the methods previously used to perform dose estimates. It also looked into the rules and regulations in place in other countries. During the course of this advisory process, the Federal Office for Radiation Protection (BfS) produced a tiered concept for discussion purposes which provides dose estimates for individual members of the general public as a result of discharge from nuclear facilities and installations as set out in Article 45 of the Euratom Basic Safety Standards (BfS 2009a). An overview of this concept is provided as an Annex.

3.2 Basic principles

The radiation protection system is changing. The German Radiation Protection Ordinance (StrlSchV) from 2001 (BMU 2012b) is based on ICRP recommendation 60 from 1991 (ICRP 1991) and the Euratom Basic Safety Standards from 1996 (EC 1996). The IAEA Basic Safety Standards (IAEA 1996) and Euratom Basic Safety Standards are currently being revised in light of the new ICRP recommendation 103 from 2007 (ICRP 2007). Once the new Euratom Basic Safety Standards have been approved and adopted, the German Radiation Protection Ordinance (StrlSchV) will also need to be revised accordingly. There are, however, major uncertainties with regard to the details of the Euratom Basic Safety Standards, which is why this recommendation examines the current legislative state. Subsequently, the new approaches in ICRP recommendation 103, which form the basis of the new Euratom Basic Safety Standards, will be examined in terms of their importance for this issue. This recommendation is structured in such a way that it can be used both with current legislation and the new exposure situation classification set out in ICRP 103, thus also rendering it suitable for use in future legislation.

3.2.1 The Euratom Basic Safety Standards

The basis of statutory radiation protection legislation in Germany and the European Community is Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation (Euratom Basic Safety Standards).

The Euratom Basic Safety Standards differentiate between radiation exposure due to practices and work activities. Article 2 (1) states the following with regard to practices: *"This Directive shall apply to all practices which involve a risk from ionising radiation emanating from an artificial source or from a natural radiation source in cases where natural radionuclides are or have been processed in view of their radioactive, fissile or fertile properties, ..."*

Article 2 (2) states the following with regard to radiation exposure during work activities: *"In accordance with Title VII it shall also apply to work activities which are not covered by paragraph 1 but which involve the presence of natural radiation sources and lead to a significant increase in the exposure of workers or members of the public which cannot be disregarded from the radiation protection point of view."*

Article 45 then demands a realistic estimate[5] of doses to the population, which forms part of this recommendation and states the following:

"*The competent authorities shall:*

(a) ensure that dose estimates from practices referred to in Article 44 are made as realistic as possible for the population as a whole and for reference groups of the population in all places where such groups may occur;

(b) decide on the frequency of assessments and take all necessary steps to identify the reference groups of the population, taking into account the effective pathways of transmission of the radioactive substances;

(c) ensure, taking into account the radiological risks, that the estimates of the population doses include:

- *assessment of the doses due to external exposure, indicating, where appropriate, the quality of the radiation in question,*
- *assessment of the intake of radionuclides, indicating the nature of the radionuclides and, where necessary, their physical and chemical states, and determination of the activity and concentrations of these radionuclides,*
- *assessment of the doses that the reference groups of the population are liable to receive and specification of the characteristics of these groups.*

(d) require records to be kept relating to measurements of external exposure, estimates of intakes of radionuclides and radioactive contamination as well as the results of the assessment of the doses received by reference groups and by the population.

[5] The German version of the Euratom Basic Safety Standards uses terms that do not reflect the intended meaning of the English text, nor the meaning as used by the SSK in this recommendation.

However, the Euratom Basic Safety Standards do not provide further specification as to how these realistic dose estimate requirements should be met. There is a guide (EC 2002) that provides information, but it is primarily intended for use in retrospectively estimating the dose to individual members of the population as a result of discharge from nuclear facilities and installations during normal operation. The proposed approach is included in Annex A-2.1.

3.2.2 The German Radiation Protection Ordinance (StrlSchV)

The requirements of the Euratom Basic Safety Standards are set out in the German Radiation Protection Ordinance[6] (StrlSchV). The German Radiation Protection Ordinance (StrlSchV) also distinguishes between radiation exposure resulting from practices and work activities.

The general need to estimate dose exposure stems from the underlying limitation of doses principle (§5 StrlSchV) as it is not possible to set a limit without knowing the value of a quantity. § 5 states the following: *“Anyone who plans or performs a practice pursuant to § 2, para. (1), subpara. 1, characters a to d or has such practice performed shall provide that the doses do not exceed the dose limits pursuant to §§ 46, 47, 55, 56 and 58. The limit of the effective dose per calendar year shall be 1 mSv pursuant to § 46, para. (1) for the protection of members of the public and to 20 mSv pursuant to § 55, para. (1), first sentence for the protection of occupationally exposed persons during the performance of their occupation.”*

The limitation of doses resulting from practices is, in principle, governed by § 46, while the limitation of doses as a result of discharge from nuclear facilities and installations during normal operation is governed in § 47 and protection against significant safety-related events is governed in § 49. § 50 governs the limitation of radiation exposure as a result of incidents in other facilities and installations and in the event of decommissioning.

§ 47 of the German Radiation Protection Ordinance (StrlSchV) - Limitation of the discharge of radioactive substances - specifically deals with estimating radiation exposure and introduces the general administrative regulation process relating to § 47 of the Radiation Protection Ordinance (StrlSchV) that was established in Germany for planning facilities and installations.

§ 47 (2) states the following: *“In the planning of facilities or installations, the radiation exposure as specified in para. (1) shall be applied for a reference person at the most unfavourable receiving points, considering the exposure pathways specified in Appendix VII, Parts A to C, the living habits of the reference person and the other assumptions; the average consumption rates specified in Appendix VII, Part B, Table 1 multiplied by the factors specified in Column 8 shall be used. With the consent of the Federal Council, the Federal Government shall issue administrative provisions relating to further assumptions to be made. The competent authority may consider the limits specified in para. (1) to have been complied with if this is demonstrated on the basis of said general administrative provisions.”*

The final sentence in § 47 (2) demands an overestimation of potential radiation exposure due to discharges from radioactive substances from facilities or installations. Within the sense of the discussion in Chapter 3.3, the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) represents an overestimation rather than a realistic determination of radiation exposure.

[6] The German X-Ray Ordinance (RöV) will not be considered in this recommendation as it is of no relevance to this consultation.

§ 49 of the Radiation Protection Ordinance (StrlSchV) stipulates dose values (incident and accident planning values) for incidents and accidents resulting from practices and incident and accident guidelines. It also refers to the Basis of Estimation for Incidents (SBG) (SSK 2004) whose intended use is to demand a conservative radiation exposure estimation. Similarly, § 50 (3) refers to the effects of incidents and accidents resulting from practices in “other facilities”, while § 50 (4) refers to a General Administrative Regulation that is still to be drawn up and that will also be based on a conservative approach.

Other specific mentions of radiation exposure estimates that are relevant to this recommendation can be found in §§ 41 and 58 of the Radiation Protection Ordinance (StrlSchV). § 58 refers to the effective dose limit for the permission of exceptional radiation exposure in workers. § 41 addresses the determination of body doses to persons in radiation protection areas.

§ 41 (1) states the following: *“The individual dose shall be measured to determine the body dose. On the basis of the conditions of exposure, the competent authority may decide that, for the purpose of determining the body doses, the following measurements or determinations shall be made either in addition or alone, divergent to the first sentence*

1. *measurement of the local dose, the ambient dose rate, the concentration of radioactive substances in the air, or the contamination of the workplace,*
2. *measurement of the activity of the body or of the excretions, or*
3. *determination of further properties of the radiation source or radiation field.*”

§§ 54 to 59 contain detailed rules on limiting occupational radiation exposure. Radiation exposure within a medical context is investigated in Chapter 4 of Part 2. This will not be considered any further in this context as it does not form part of this recommendation (cf. Chapter 3.3). Exceptions to this are the circumstances described in §§ 41 and 58 of the German Radiation Protection Ordinance in which modelling is to be used to prospectively or retrospectively estimate the level of radiation exposure to individual persons.

Despite the fact that they are not specifically mentioned in the Radiation Protection Ordinance (StrlSchV), radiation exposure estimates resulting from practices form the basis for determining exemptions, surface contamination values, and clearance values. Based on the criterion of not exceeding a trivial dose of several 10 μSv per calendar year, these values are derived by the prospective modelling of potential radiation exposure for workers and members of the general public. General details about the approach used are set out in (Dymke 2002), while information about deriving exemptions is listed in (IAEA 1988, EC 1993) and details on deriving clearance values are provided in (Deckert et al. 2000, SSK 1998, Thierfeldt and Kugeler 2000, Thierfeldt et al. 2003).

Radiation exposure during work activities is dealt with in Part 3 of the Radiation Protection Ordinance (StrlSchV). Here, a clear distinction is made between estimating and determining radiation exposure.

§ 95 (1) of the Radiation Protection Ordinance (StrlSchV) requires the responsible person to have a radiation exposure estimation or determination performed at workplaces. The scope and method for estimating radiation exposures at workplaces is only rudimentally outlined in the Radiation Protection Ordinance (StrlSchV). § 95 (10) stipulates that *“...the person responsible according to para. (1) shall determine the radon-222 exposure or the potential exposure to alpha energy and the body dose in a suitable manner by measuring the local dose, the ambient dose rate, the concentration of radioactive substances or gases in the air, the contamination of the workplace, the individual dose, the body activity or the activity of excretion...”*. § 95 (10) gives the competent authorities the option to stipulate measuring methods and places of measurement for the places of work stated in Appendix XI of the Radiation Protection Ordinance (StrlSchV). The Radiation Protection Ordinance (StrlSchV) does not specify any further procedures.

There are no requirements set for an estimation of the radiation exposure in the context of residues requiring surveillance. Instead, the specific activity of materials is assessed to see if the disposal of residues requiring surveillance may cause the effective dose constraint for the general public of 1 mSv per calendar year to be exceeded. The surveillance limits in Appendix XII, Part B of the Radiation Protection Ordinance (StrlSchV) serve as the reference levels. The competent authority may stipulate technical methods, suitable measuring methods and other requirements, in particular those for the determination of representative measuring values for the specific activity which can be used to ensure that the surveillance limits described in Annex XII Part B are met.

A release pursuant to § 98 of the Radiation Protection Ordinance (StrlSchV) is required for the disposal of residues requiring surveillance. A release may only be granted if the radiation exposure of members of the general public does not exceed an effective dose of 1 mSv per calendar year as a result of such disposal or utilisation. Proof that the indicative dose of 1 mSv per calendar year has been complied with must be furnished by applying the principles set out in Appendix XII, Part D of the Radiation Protection Ordinance (StrlSchV). These principles state that the level of radiation exposure of individual members of the general public is to be determined as set out below:

1. Realistic exposure pathways and exposure assumptions are to be applied.
2. Insofar as the exposure pathways in accordance with Appendix VII, Part A are taken into account, the assumptions specified in Appendix VII, Part B, Table 1, Columns 1 to 7 and Table 2 shall be taken as a basis.
3. For the recycling of residues, all exposure shall be included that could occur at any stage of the intended recycling path.
4. For the disposal of residues, all exposure shall be included that could realistically occur on the intended disposal path through the treatment, storage and final disposition of the residues.
5. With properties that are contaminated by residues, all exposures shall be included that could realistically occur considering the specific location conditions.
6. The dose coefficients from the compilation in the Bundesanzeiger No. 160a and b of 28 August 2001 shall be used.

According to the provisions of Part 3, Chapter 4 of the German Radiation Protection Ordinance (StrlSchV), anyone who employs flying personnel shall determine the cosmic radiation said personnel is exposed to during the flight, insofar as the effective dose through cosmic radiation may exceed 1 mSv per calendar year.

3.2.3 Administrative regulations, directives and other provisions

Below the ordinance level, administrative regulations and directives serve to draft the provisions of the German Radiation Protection Ordinance (StrlSchV).

In terms of estimating radiation exposure from practices, these include the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV), the Basis of Estimation for Incidents (SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV), the Calculation Guide Mining (BglBb), the Guideline for Physical Radiation Protection Control (RiPhyKo) relating to §§ 40, 41 and 42 of the Radiation Protection

Ordinance (StrlSchV) and to § 35 of the X-ray Ordinance (RöV), and, in terms of estimating radiation exposure from work activities, relating to the Guideline for Monitoring Radiation Exposure during Work Activities pursuant to Part 3, Chapter 2 of the Radiation Protection Ordinance (StrlSchV) (Work Activities Guideline).

3.2.3.1 General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV)

The application scope of the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) (BMU 2012a) is defined as follows: *"This General Administrative Regulation applies to the estimate of radiation exposure pursuant to § 47 (2) of the Radiation Protection Ordinance (StrlSchV). The results shall be used in licencing procedures to establish whether radiation protection supervisors have planned the technical design and operation of their plants or facilities such that the radiation dose limits specified in § 47 (1) of the Radiation Protection Ordinance (StrlSchV) are not exceeded when discharging radioactive substances to air and water."*

The General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) stipulates the models and parameters used to calculate radiation exposure in such a way that, when applied, the anticipated human radiation exposure cannot be underestimated. It is highly conservative and not a realistic estimate.

Radiation exposure for the reference persons of the age groups stated in Appendix VII, Part B, table 1 of the Radiation Protection Ordinance (StrlSchV) is calculated at the most unfavourable receiving points. The most unfavourable receiving points are the locations and/or vicinities of plants or facilities which discharge radioactive substances into the environment where the highest radiation exposure of the reference person is expected due to spending time or consuming food that was produced there. Unfavourable receiving points take account of all realistic uses as well as potential future changes in terms of settlement or future use, provided they cannot be fundamentally disregarded for environmental reasons. Further details on the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) are available in Annex A.1.2.

3.2.3.2 Basis of Estimation for Incidents (SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV)

The Basis of Estimation for Incidents (SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV), revision of Chapter 4: Calculation of radiation exposure (SSK 2004) is used to estimate the radiation exposure of reference persons at the most unfavourable receiving points. Reference persons used to estimate doses within the sense of § 49 of the Radiation Protection Ordinance (StrlSchV) are persons from the age groups stated in Appendix VII, Part B of the Radiation Protection Ordinance (StrlSchV) with living habits as described in tables 2 and 3. The most unfavourable receiving points are the locations in the vicinity of plants which discharge radioactive substances into the environment where, under realistic usage conditions, the highest radiation exposure of the reference person is expected due to spending time or consuming food that was produced there. Usage options also include potential future changes in terms of settlement or future use, provided they cannot be fundamentally disregarded for ecological reasons.

3.2.3.3 Calculation Guide Mining (BglBb)

The Calculation Guide Mining was developed in the mid-1990s. In 1999, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) forwarded the Calculation Guide Mining to the German states of Saxony, Saxony-Anhalt and Thuringia for testing (BMU 1999a,b) which was mainly conducted from a practical perspective by Wismut GmbH in its remediation projects.

In 2010, the Federal Office for Radiation Protection (BfS) published a revised version. Here is a quote from the introduction: *"Both Calculation Guides were widespread during the last decade and have established themselves successfully in the assessment of radiation exposure from environmental radioactivity due to mining since their publication. This is essentially due to the fact that this guide was the first to specify calculation models and parameters enabling a "realistic but sufficiently conservative" assessment of intervention situations in radiation protection according to the SSK."*

The Calculation Guide Mining applies to dose estimates for humans in intervention situations due to mining residues. The Calculation Guide Mining is to be used to

- prove compliance of dose limits for employees,
- prove compliance of dose reference levels for members of the public,
- perform dose estimations at mining residues,
- plan and optimise exposure-reducing measures.

When applying the calculation guide, only those scenarios and exposure pathways should be taken into consideration that are actually relevant in each specific case.

The exposure scenarios and pathways, calculation parameters and radionuclides to be taken into consideration when estimating radiation exposure resulting from mining should be primarily chosen using qualitative assessments. Any cases of doubt should be clarified by performing further investigations into the location and exposure scenarios.

Radiation exposure must be assessed for reference persons at the most unfavourable receiving points. The most unfavourable receiving points are those where the highest radiation exposure of the reference person is to be expected for the exposure scenarios and pathways under inspection while also accounting for realistic uses and behaviour. The most unfavourable receiving points shall be determined in the precise application. Further details of the approach set out in the Calculation Guide Mining are available in Annex A-1.3.

3.2.3.4 Guideline of Physical Radiation Protection Control (RiPhyKo) relating to §§ 40, 41 and 42 of the Radiation Protection Ordinance (StrlSchV) and § 35 of the X-ray Ordinance (RöV)

The Guideline of Physical Radiation Protection Control (BMU 2007) is only mentioned here for the sake of completeness as it has no relevance to this recommendation (cf. Chapter 3.3).

3.2.3.5 Guideline for Monitoring Radiation Exposure during Work Activities pursuant to Part 3, Chapter 2 of the Radiation Protection Ordinance (StrlSchV) (Work Activities Guideline).

The Guideline for Monitoring Radiation Exposure during Work Activities pursuant to Part 3, Chapter 2 of the Radiation Protection Ordinance (StrlSchV) (Work Activities Guideline) published by the Federal Office for Radiation Protection (BfS) on 15 December 2003 (BMU 2003) should be mentioned in connection with estimating radiation exposure from work activities. This guideline stipulates the type, scope, methods and administrative approach for

- estimating radon-222 exposure or body dose that can be attributed to one of the fields of work activity specified in Parts A and B of Appendix XI of the Radiation Protection Ordinance (StrlSchV), and for

– estimating radon-222 exposure and body dose for persons engaged in work activities requiring a declaration.

The guideline is applied to German administrative procedures within the scope of Part 3 Chapter 2 of the Radiation Protection Ordinance (StrlSchV) (see ib. Chapter 1).

It distinguishes between a conservative estimate and a best estimate, where a conservative estimate is "*the assessment of radiation exposure to a single person at their place of work over the period of a calendar year*". *"A conservative estimate must be representative for the work activities performed by the person. The assumptions on which a conservative estimate is based must be conservative in terms of the actual exposure conditions present."*

A best estimate of radiation exposure is based on measuring values from fixed or portable measuring equipment that "*are representative for the person's durations of stay at their place(s) of work*" and contains statements about the relevance of exposure pathways:

"*When estimating radiation exposure for work activities pursuant to Part B of Appendix XI of the Radiation Protection Ordinance (StrlSchV), all exposure pathways that account for more than ten per cent of total exposure shall be deemed relevant and must be taken into consideration. Relevant exposure pathways generally include external radiation exposure and the inhalation of dust, smoke or aerosol particles. Ingestion generally accounts for less than ten per cent."*

"Every exposure pathway must be taken into consideration when estimating radiation exposure. If work activities that can be attributed to the fields of work activity specified in Part B of Annex XI of the Radiation Protection Ordinance (StrlSchV) are listed in the fields of work activity in Part A of Annex XI of the Radiation Protection Ordinance (StrlSchV), then radon-222 exposure should be taken into consideration."

"Exposure pathways that contribute less than ten per cent towards total exposure can be ignored during an estimate. This therefore means that ingestion can usually be overlooked."

The derivation of reference levels for workplaces pursuant to Radiation Protection 95 (EC 1999) also serves to limit radiation exposure due to natural radioactivity.

In order to identify industrial processes which must be considered for radiation protection reasons, the guide derived reference levels of specific activities in order to support the implementation of Title VII of the Euratom Basic Safety Standards (EC 2002) which, if exceeded, can lead to workplace exposure above certain dose values.

Three scenarios were taken into consideration: The exposure of aggregates or stock, exposure due to encrustations and residues resulting from high-temperature processes, and exposure due to process tanks and piping.

For each of these three scenarios, (relevant) exposure pathways (direct exposure, inhalation of dust or smoke, ingestion of dust, inhalation of radon) were compiled and given parameters. The parameter sets differentiate between "normal assumptions" and "improbable assumptions". These assumption parameters are, in turn, assigned a factor between 3 and 5. Even with the "normal assumptions", the parameters are stipulated in such a way as to ensure a certain level of conservatism of the results. The aim of this is not to estimate actual exposure, but to compare materials in terms of potential radiation exposure of workers during work activities.

3.2.3.6 Other provisions

In order to limit potential radiation exposure of individual members of the general public to natural radioactivity in residues (Part 3, Chapter 3 of the Radiation Protection Ordinance (StrlSchV)), the values of the specific activity of these residues must be determined. A comparison with surveillance limits in the Radiation Protection Ordinance (StrlSchV) then determines how these residues should be monitored.

The purpose of deriving surveillance limits was to determine the points from which "*radiation protection measures should be considered*" for specific activities when disposing of substance flows with enhanced natural radioactivity that occur in Germany. This objective generally required a conservative approach. As there were no specific cases to be considered, fictitious reference persons (members of the general public) had to be used whose behaviour and living habits are in line with statistics pertaining to real people in Germany. The scenarios and scenario parameters used to derive surveillance limits were designed in such a way that they broadly provide conservative coverage of actual conditions in individual cases (e.g. a house is located 20 metres away from a waste site and a well is located 20 metres away from a landfill). Conservatism also forms part of the assumption of an equilibrium of activity in the decay series (exception: special case involving Pb-210 enrichment), where the maximum specific activity of the U-238 and Th-232 series is always assumed when applying model calculations to materials with radioactive disequilibria. Excessive conservatism was avoided, however, by not including safety margins.

The SSK recommendation "Principles and methods for consideration of statistical uncertainties in the determination of representative values of the specific activity of residues" (SSK 2005b) created the basis that accounts for the particular problem of variability and statistical uncertainty (cf. Chapter 3.4.4) for the option to stipulate methods for determining representative measuring methods as set out in § 97 (3) of the Radiation Protection Ordinance (StrlSchV).

This recommendation defines the representative specific activity of batches as a reference value for proving compliance with the indicative dose, which includes Part C of Appendix XII of the Radiation Protection Ordinance (StrlSchV). This therefore implicitly accounts for the representative specific activity defined by the provisions of this recommendation as a measurand for realistically estimating radiation exposure pursuant to Part D of Appendix XII of the Radiation Protection Ordinance (StrlSchV).

In the recommendation, the representative specific activity, which is (slightly) conservative from an assessment perspective, is chosen as the upper confidence limit of the expectation value. On top of that, the recommendation contains information about sampling and sample measurements.

In its annual parliamentary report, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) informed the German Bundestag and Bundesrat about radiation exposure in Germany and the development of radioactivity in the environment. The Precautionary Radiation Protection Act (StrVG) from 19 December 1986 (BMU 2008) is taken as the legal basis. This information is also sent to the European Union within the scope of the obligations of Article 35 and 36 of the Euratom Treaty from 25 May 1957. Realistic estimates of the various radiation exposure situations are a key pillar of this statutory reporting process. Estimates portray a falsifying image when it comes to reporting (cf. Chapter 3.2.5).

3.2.4 ICRP recommendation 103

In 2007, the ICRP issued recommendation 103 (ICRP 2007) which mostly confirms the previous principles of radiation protection. However, ICRP 103 included changes to the categorisation of radiation exposure which also have an impact on the realistic estimation of radiation exposure.

While ICRP 103 retains the three categories relating to exposure to the general public, workers and patients, it no longer differentiates exposure to natural or artificial radioactivity (practices or work activities). Instead it only differentiates between planned exposure situations, emergency exposure situations and existing exposure situations which are designed to cover the entire spectrum of exposure situations.

– Planned exposure situations arise from the planned operation of a source, including decommissioning, disposal of radioactive waste, and remediation of previously polluted areas. Ongoing practices are planned exposure situations linked to the planned introduction and operation of sources. This type of exposure situation also includes ones that were previously classified as work activities.
– Emergency exposure situations are unexpected situations that arise as a result of incidents and accidents while carrying out a planned situation, of past practices or work activities, or as a result of a malicious act which require immediate (emergency) measures in order to avoid or reduce adverse consequences on the health, safety, quality of life and property of people and the environment. This includes situations that justify immediate action to reduce the risk.
– An existing exposure situation is a situation of exposure which already exists when a decision on the need for control needs to be taken. Examples of an existing exposure situation include natural radioactivity and radiation, and the consequences of past human activities.

The three basic principles of radiation protection have been retained in ICRP 103.

– Principle of justification: Any decision that alters the radiation exposure situation should do more good than harm.
– Principle of optimisation of protection: The likelihood of incurring exposure, the number of people exposed and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.
– The principle of application of dose limits: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission.

The principles of justification and optimisation apply to all three categories of exposure situations, whereas dose limits only apply to planned exposure situations. In emergency and existing exposure situations, the limits that apply to planned exposure situations may be exceeded or cannot be complied with. In such cases, the principles of optimisation shall apply.

This means that the best-possible level of protection in the given circumstances should be achieved by maximising the gap between good and harm. In order to avoid inappropriate optimisation method results, limits on doses or risks to persons due to a certain source (dose or risk constraints as well as reference levels) should be put in place.

The ICRP uses the terms dose constraint for planned exposure situations and reference level for emergency and existing exposure situations in conjunction with the optimisation of radiation protection to limit individual doses. Both dose constraint and reference level are defined in terms of individual doses. The intention is to comply with or to not exceed, the corresponding values. Notwithstanding that, the aim is to reduce all doses to values that are as low as reasonably achievable, taking into account economic and societal factors.

The dose limit for planned exposure situations stipulates the dose or risk limit which must not be exceeded. Below the dose limits, constraints are defined as reference levels that should not be exceeded. The principal of optimisation applies to levels below the constraints.

In emergency exposure situations or existing controllable exposure situations, the reference level indicates the dose or risk limit which, when exceeded, should be considered inappropriate exposures and, if not reached, action should be taken to optimise protection levels. The exact figures to be used as a reference level depend on the circumstances of the considered exposure.

Table 3.1 shows the various types of dose restrictions used in the ICRP protection system (limits, constraints, reference levels) in relation to type of exposure situation and exposure category. Risk constraints are also included in planned exposure situations in order to account for potential exposures.

Table 3.1: Constraints and reference levels used in the ICRP's protection system (ICRP 2007).

Exposure situation	Occupational exposure	Exposure of the general population	Medical exposure
Planned exposure situation	Dose limit Constraint	Dose limit Constraint	Diagnostic reference level [d] (Constraint [e])
Emergency exposure situation	Reference level [a]	Reference level	N/A [b]
Existing exposure situation	N/A [b,c]	Reference level	N/A [b]

a Long-term measures should be considered as part of planned occupational exposures

b Not applicable

c Exposures resulting from long-term remediation measures or prolonged work in affected areas should be dealt with as part of planned occupational exposures

d Patients

e Only carers, comforters and volunteers in research

Figure 3.1 shows the relationship between constraints and reference levels and optimisation of protection. The ICRP only recommends bands for reference levels in the event of emergency and existing exposure situations: 20 mSv to 100 mSv p.a. for emergency exposure situations, and 1 mSv to 20 mSv p.a. for existing exposure situations. Within the scope of optimising protection, the long-term goal is to achieve a reference level of 1 mSv p.a.

Also within this scope, the ICRP recommends that particular emphasis should be placed on reducing the number of persons whose dose exceeds the reference levels (Fig. 3.2). Measures to reduce the dose should be assessed on the basis of the residual dose exceeding the reference levels after implementation (Fig. 3.2). This requires knowledge of a dose distribution among exposed groups of people. Optimisation is impossible if radiation exposure estimates do not reflect reality.

The ICRP also recommends placing particular emphasis on reducing the exposure distribution percentiles above the reference levels when implementing measures to optimise protection in emergency or existing exposure situations. The priority here is to reduce the percentiles, but this is not possible without a realistic, probabilistic estimate of radiation exposure among an affected group of people.

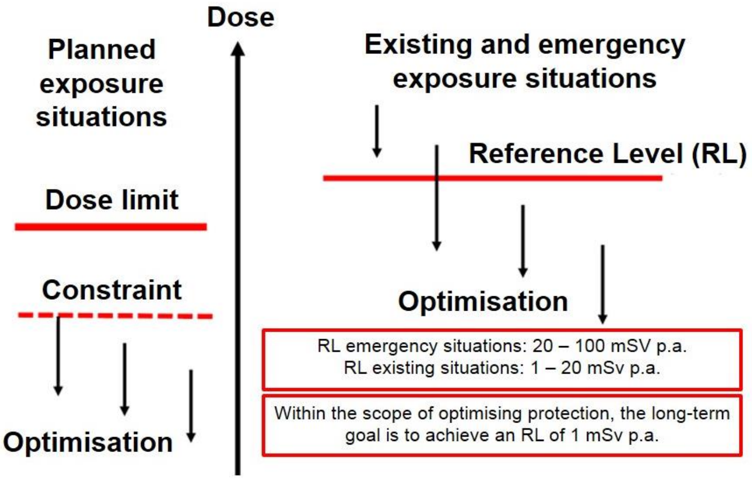

Fig. 3.1: System of the dose limits, constraints and reference levels and of optimisation of protection as defined in ICRP 103.

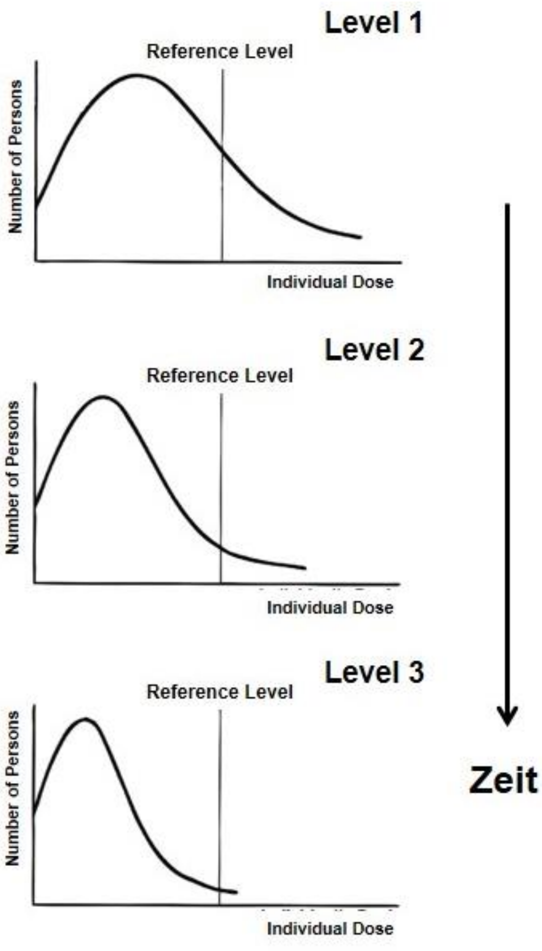

Fig. 3.2: Development of dose distribution among an exposed group within the scope of optimisation as a function of time (ICRP 2007): The use of a reference level in an existing exposure situation and the evolution of the distribution of individual doses with time as a result of the optimisation process).

With regard to realism in estimating radiation exposure, the ICRP lays down the following requirement in Chapter 6.6.5 *Compliance with the intended standard of protection*:

"*(320) The measurement or assessment of radiation doses is fundamental to the practice of radiological protection. Neither the equivalent dose in an organ nor the effective dose can be measured directly. Values of these quantities must be inferred with the aid of models, usually involving environmental, metabolic, and dosimetric components. Ideally, these models and the values chosen for their parameters should be realistic, so that the results they give can be described as* '*best estimates'. Where practicable, estimates and discussion should be made of the uncertainties inherent in these results.*"

The ICRP included this requirement word for word in § 264 of Chapter 7.5 *Assessment of doses* of ICRP publication 60 (1991).

3.2.5 Summary and evaluation

Realistic radiation exposure estimation was demanded both by ICRP 60 from 1991 and by the Euratom Basic Safety Standards from 1996. ICRP 103 and the present draft of the Euratom Basic Safety Standards (EC 2012) reiterate this request. The ICRP (1991, 2007) defines the phrase "as realistically as possible" as meaning that the results of radiation exposure estimates should be understood as "best estimates" in a metrological sense while also referring to the importance of stating uncertainties.

Germany has a system in place for estimating radiation exposure that has grown over time. It is neither consistent nor suited to realistically estimating radiation exposure, thus rendering it insufficient for meeting the Euratom Basic Safety Standards' realism requirement.

As the Euratom Basic Safety Standards and IAEA Basic Safety Standards are currently being revised on the basis of ICRP 103, the need for realism should also be sufficiently incorporated into a revision of the Radiation Protection Ordinance (StrlSchV) which will be due in the near future. This recommendation is designed to support that process.

In Germany, radiation exposure estimations are currently conducted on the basis of the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV), on the Basis of Estimation for Incidents (SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV), and the Calculation Guide Mining (BglBb) when deriving clearance values, exemptions and surveillance limits, and when reporting to the parliament and the EU. The methods used to perform estimates vary widely in terms of their realism. This is because the need for a conservative or realistic radiation exposure estimate depends on the intended objective of the assessment.

When planning nuclear facilities and installations, the methods used in the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) and the Basis of Estimation for Incidents (SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV) are - to differing extents - extremely conservative. When retrospectively estimating radiation exposure due to emissions from approved handling and approved facilities, the methods used in the General Administrative Regulation are applied using current derived data and weather data and then published in the parliamentary report as data for mean radiation exposure to the general public; e.g. Fig. 1 of the 2010 parliamentary report (BMU 2012c). Nevertheless, the results of these calculations neither represent the mean exposure to the general public, nor the actual exposure to the most exposed members of the general public.

In the opinion of the SSK, estimates for reporting purposes should be as realistic as possible by providing actual radiation exposure figures.

The mean radiation exposure data to the general public stated in the parliamentary report (Fig. 3.3) gives rise to a different problem as it compares two quantities with one another that refer to different reference groups of the population, meaning that they cannot actually be compared with one another.

The figure below compares realistically calculated mean radiation exposures from natural sources with those resulting from X-ray procedures and diagnostic nuclear medicine. Radiation exposures from the latter are unsuitable as a mean for comparison purposes as the determination of the mean includes all those who have not been subject to diagnostic measures and, therefore, have not been exposed to radiation. Radiation exposure figures for nuclear facilities refer to reference persons at the most unfavourable receiving points and are neither representative of radiation exposure in the vicinity of facilities, nor of the general population in Germany. Mean exposures due to the Chernobyl nuclear accident and as a result of the global fallout from nuclear weapons testing can however be considered to be realistic mean values.

Beyond the question of the realism of the data, these inconsistencies are indicative of the need to clearly define the target quantity and not to compare different quantities with one another.

The SSK would also like to point out another reporting deficit. No statements are made regarding the uncertainties of data and no distributions of radiation exposure among the general population are stated when referring to contributions to radiation exposure.

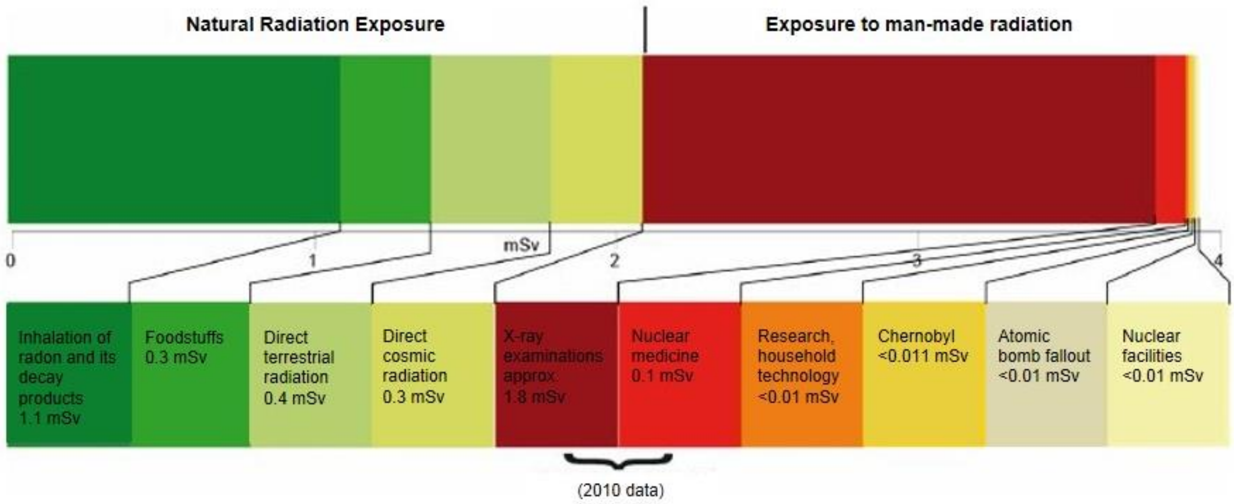

Fig. 3.3: Effective annual dose to a person due to ionising radiation in mSv in 2011, mean value for the German population and grouped by radiation source (BMU 2013).

Prospective dose estimates for planning emergency protective measures (§§ 51 and 53 of the Radiation Protection Ordinance (StrlSchV)) have not been mentioned until now. In this regard, the underlying dose calculations must be based on a scenario that is as realistic as possible and they must generally be as realistic as possible in order to be able to react appropriately in the event of an emergency and to avoid inappropriate measures being taken that bear the risk of consequential damage.

When planning practices, German legislation is not uniformly conservative; when deriving clearance values and exemptions, assumptions used for potential radiation exposure estimate models and parameters are largely more realistic than those used when planning and operating nuclear facilities and installations.

In contrast to the methods used for practices, the methods used to estimate radiation from natural radiation sources during work activities is far more realistic. German legislation encourages the provision of realistic exposure estimates in cases where certain thresholds may be exceeded. Whether or not such a situation is present can only be determined by a conservative dose estimate, though.

If specific workers (workplaces) are considered, the Radiation Protection Ordinance (StrlSchV) encourages suitable measurements as a basis for estimations. Estimates can also be made using (conservative) assumptions.

The demand for realism is implemented by only including relevant pathways in the exposure estimate and by using representative specific activities as well as realistic parameters without safety margins.

Realistic estimates also contain conservative elements, though, because they involve reference persons who spend time at the most unfavourable receiving points and whose living habits and behaviour lead to exposure deemed conservative for most real people when taking precautionary actions into account.

An analysis of dose estimate uncertainties or any dose distribution figures for work activities are currently not available.

This SSK recommendation is designed to promote the future implementation of the Euratom Basic Safety Standards' requirements in Germany and to promote the introduction of a reasonable and consistent method for estimating radiation exposure. The current German legislation still distinguishes between practices and work activities. ICRP 103 makes no such distinction, nor does it differentiate between natural or artificial radioactivity in order to structure the radiation protection system by categorising the various exposure situations into planned, existing and emergency situations. Therefore, this recommendation already adopts the exposure situation categorisation set out in ICRP 103. The recommended new system should be coherent and meet both current and future requirements.

3.3 Application scopes and purposes of estimating exposure

The term "estimate" has various connotations. The *Work Activities Guideline* (BMU 2003) provides the most accurate description as it breaks the broader term "determination" down into "conservative estimate" and "best estimate".

"Conservative estimate" is used for conservatively considering potential exposures in order to determine whether limits or constraints are always complied with and, if not, whether a more realistic estimate of the true radiation exposure values is required.

In this recommendation, the SSK understands a conservative estimate to mean a deterministic, conservative modelling of potential maximum exposures that do not need to be as realistic as possible. The broader term determination is not used in this recommendation as it suggests that conservative estimates would have to be linked to reality.

An "estimate" is the estimation of the actual exposure value and quantification of the uncertainty of said estimate according to GUM (JCGM 2007a) or GUM Supplement 1 (JCGM 2007b). Estimates are performed using radiation exposure calculations based on models, measurements and other information.

The realistic radiation exposure estimate method recommended here mainly involves radioecological modelling to estimate radiation exposure among the general public. The "exposure to workers" category is only involved if radiation exposures have to be estimated by (radioecological) modelling rather than individual dosimetry measurements methods. The "exposure to patients" category does not form part of this recommendation.

Exposure is split into 3 categories, as set out in ICRP 103:

- Planned exposure situations: Nuclear technology and the entire fuel cycle, the use of radioactivity in medicine, research and other technology, the remediation of contaminated sites, the effects of NORM and TENORM industries, and the planning, erection and operation of interim and final nuclear waste repositories.
- Emergency exposure situations: incidents and accidents involving natural and artificial radionuclides, malicious acts, and lost sources.
- Existing exposure situations: Long-term effects of accidents and incidents and accidents involving natural and artificial radionuclides, and including optimisation of protection.

Dose estimates can be of a prospective or retrospective nature, or they can refer to the current exposure situation. It is important to distinguish between prospective and retrospective statements for each exposure situation as information is available retrospectively but not prospectively.

Radiation exposure has to be estimated for a wide range of different applications. Within the scope of ICRP 103, it is of little importance whether radiation exposure is caused by natural or artificial radionuclides or fields of ionising radiation. This recommendation investigates exposure situations where radioecological aspects need to be included when estimating exposure, i.e. situations where natural and artificial radiation fields and radionuclides in the natural environment or in areas changed by mankind give rise to radiation exposure among humans. In this respect, reference is made to previous SSK recommendations (SSK 1992, SSK 1997) where radioecology is used to describe the pathways radionuclides take from sources to drains, in particular their pathways to humans and other living beings with the aim of understanding and quantifying estimates for radiation exposure caused by radioactivity in the workplace or in the environment.

Aspects of radiation exposure estimations that are beyond the scope of radioecology, in particular the stipulation of dose coefficients and other conventional quantities, do not form part of this recommendation's application scope.

Table 3.2 shows the assignments of application scopes to the three exposure situations set out in ICRP 103 and in current legislation for which radiation exposure estimates are required or, as is the case with licencing procedures, requested.

Table 3.2: Application scopes for estimating radiation exposure using (radioecological) modelling, the assignment of the estimates to exposure situations pursuant to ICRP 103, and their purposes according to current legislation.

	Application scopes	ICRP [a)]	Purpose
I	**Information**		
I.1	**Natural radiation exposure**	EX	Parliamentary report
I.2	**Nuclear weapons testing**	EX	Parliamentary report
I.3	**Chernobyl**	EX	Parliamentary report
I.4	**Nuclear technology, technology, research, medicine (for reporting purposes)**		
I.4-1	Radiation exposure among reference groups or members of the general public resulting from practices during normal operation	P	EU Art. 45 parliamentary report
I.4-2	Radiation exposure among reference groups or members of the general public resulting from practices after incidents and accidents	EX	EU Art. 45 parliamentary report
I.5	**Epidemiological research**		
I.5-1	Epidemiological research; cohort and case-control studies	EX, EM	Science
I.5-2	Epidemiological research; ecological studies	EX	Science
II	**Limitation of doses by limit, constraint, reference and indicator values: Planning and monitoring**		
II.1	**Construction and operation of nuclear plants and facilities subject to authorisation as stipulated in § 47 of the Radiation Protection Ordinance (StrlSchV)**		
II.1-1	Licence - normal operation	P	§§ 13, 46 and 47 of the Radiation Protection Ordinance (StrlSchV)
II.1-2	Licence - design basis accident	P	§ 49 of the Radiation Protection Ordinance (StrlSchV)
II.1-3	Monitoring - normal operation	EX	Licencing conditions
II.2	**Emergency management**		General: §§ 51 to 58 of the Radiation Protection Ordinance (StrlSchV)
II.2-1	Stipulation of protective measures - short-term - prospective (based on forecasts)	EM	
II.2-2	Stipulation of protective measures - short-term - retrospective (based on activity measuring values)	EM	
II.2-3	Remediation	EX	
II.2-4	Stipulation of protective measures - long-term (elimination of use constraints, resettlement)	EM, EX	

	Application scopes	ICRP [a)]	Purpose
II.2-5	Rescue operations - workers	EM	§ 59 of the Radiation Protection Ordinance (StrlSchV)
II.3	**Clearance**		
II.3-1	Derivation of clearance values	P	§ 29 of the Radiation Protection Ordinance (StrlSchV)
II.3-2	Clearance on an individual basis	P	§ 29 of the Radiation Protection Ordinance (StrlSchV)
II.4	**Long-term safety analysis at final nuclear waste repositories**		
II.4-1	Current applicable law	P	BMU 2010
II.4-2	State of discussion for forecasts over foreseeable periods of time	P	ESK/SSK + ICRP
II.4-3	State of discussion for long-term estimates[b)]	P	
II.5	**Radiologically contaminated sites**		
II.5-1	Workers		§ 95 et seqq. of the Radiation Protection Ordinance (StrlSchV)
II.5-2	Members of the general public	P, EX	Calculation Guide Mining (BglBb)
II.5-3	Derivation of trigger and action values	EX	*(does not exist yet)*
II.5-4	Individual case / current situation	EX	
II.5-5	Individual case / during remediation	EX	
II.5-6	Individual case / future (with/without remediation)	EX	
II.6	**Standard**		
II.6-1	Workers	EX, P	§§ 95 and 96 of the Radiation Protection Ordinance (StrlSchV)
II.6-2	Members of the general public	P	§§ 97, 98, 101, 102 of the Radiation Protection Ordinance (StrlSchV)

a) This column characterises exposure situations based on ICRP 103:
P: planned exposure situations, EX: existing exposure situations, EM: Emergency exposure situations

b) The potential radiation exposure estimates for long-term final nuclear waste repository and contaminated site assessments only constitute indicator values within the scope of long-term safety assessment considerations

All of the applications set out in Table 3.2 are investigated in detail in this recommendation (see Chapter 3.5).

The following items are not included in this recommendation:

– Exposure estimates of workers during practices,

- Exposure estimates of patients during the diagnostic and therapeutic application of radiation and radionuclides,
- Assessment of risk subsequent to exposure using radiation-epidemiological tables and clarification of claims for damages.

At times, radiation exposure of workers during work activities is also of an “ecological exposure” nature, thus necessitating its inclusion in this recommendation. In terms of spas and, in particular, radon therapy, patients may be exposed to radiation covered by this recommendation. In Germany, the exposure of flying personnel and passengers to radiation is estimated by using standardised methods which are to be understood as being realistic. This recommendation does not cover this topic in further detail.

The same principles and methods can be applied to radiation exposures to the general public due to:

- Radioactivity in technical products (intended and unintended introduction),
- Other man-made sources,
- Radioactivity in foodstuffs,
- Transport of radioactive material: Impact on the population,
- Other practices (monitoring systems, material testing).

The target groups of best and conservative radiation exposure estimates are diverse and extend beyond the categories “workers”, “patients” and “the general public”. Depending on the issue at hand, the target group may be a real or hypothetical, critical group, a real or hypothetical “most exposed individual” at the most unfavourable receiving point, or reference persons or real persons at the most unfavourable receiving point or at an arbitrary location. The characteristics of reference persons may form the mean or extreme characteristics, e.g. the 95th percentile. This is unimportant, however, when estimating radiation exposure.

In this respect, the terms reference person as defined by ICRP 23 and representative person according to ICRP 101 should be investigated further. *Fig. 1.1* “*Relationships between various points of reference for protection of the public*” of ICRP 108 (ICRP 2008) illustrates the difference between the reference person and the representative person. According to the ICRP, a reference person combines both the male and female characteristics of the reference man (ICRP 2002) for which tissue equivalent doses and the effective dose have been defined and to which dose coefficients apply. The dose quantities to the reference person are used for comparison with limits, constraints and reference levels. In planned, existing and emergency exposure situations, a representative person - be it a real or reference person - is characteristic for the radionuclide absorption and external exposure that vary depending upon dietary habits and durations of stay, thus rendering them characteristics of the representative person.

According to ICRP 101, the representative person should receive a dose that is representative of more highly exposed persons of the general public. The dose to the representative person is equivalent to the average dose to persons in the “critical group” in past ICRP recommendations, and therefore replaces it.

It would therefore seem logical to refer to representative reference persons rather than reference persons for estimates of the doses obtained by more highly exposed persons. The SSK is aware that German and international legislation does not always share this view of the reference person and representative person, which is why there is some confusion as to the terminology used. The SSK therefore suggests that the term representative reference person be discussed internationally and introduced into German legislation.

The aim of realistic radiation exposure estimation is to provide as accurate an estimate (best estimate) of the true value of the output quantity as possible based on the information available, and to quantify the uncertainty of the estimate for a given person at an arbitrary location in a real or hypothetical exposure situation, i.e. for a representative reference person or representative real person.

Estimates can be used for a number of different purposes, e.g. to prove compliance with limits and constraints, to perform constraint tests upon request by official bodies, in the event that probability thresholds for stochastic effects and thresholds for deterministic effects are exceeded, and for reporting and scientific investigations. In terms of requirements, estimates may be conservative in order to ensure compliance with dose restrictions when planning facilities and practices, or they can be used to estimate doses for existing facilities or determine circumstances by means of model calculations or measurements.

Every best or conservative estimate serves a certain purpose[7]. Examples of such purposes in connection with radiation exposure include:

- Surveillance of workers when performing practices and work activities requiring surveillance on the basis of the Euratom Basic Safety Standards (EC 1996), the Radiation Protection Ordinance (StrlSchV) (BMU 2012b) and the X-ray Ordinance (RöV) (BMU 2011b).
- Fulfilment of public administration duties such as the requirements set out in Articles 35 and 36 of the Euratom treaty (Euratom 1957).
- Precautionary radiation protection measures for the general public as set out in the Precautionary Radiation Protection Act (StrVG) (BMU 2008).
- Estimation of natural and man-made radiation exposure to the general public.
- Estimation of normal or background values.
- Proof of fulfilment of individual requests from official bodies.
- Exposure situation investigations during intervention, remediation and resettlement.
- Evaluation of certain situations where increased levels of exposure are present or suspected.
- Monitoring of volunteers in medical research, including epidemiology.
- Estimation of the probability of causation when investigating claims for damages.
- Comparison of various different options for further action in terms of sustainability.
- Estimation of dose-risk relationships in epidemiology.
- Medical applications in diagnostics and therapy.
- Assessment of existing exposure situations and existing facilities.

When estimating radiation exposure, the purpose gives rise to requirements necessitating differing approaches for calculating the value to be ascertained. Two purposes can be identified here:

[7] "Purpose" describes the motivation for a certain practice or behaviour.

- Investigation of radiation exposure relative to given levels (limits, constraints, reference levels, trigger values, etc.). This (explicit or implicit) reference means that the radiation exposure estimation has a specific (quantitative) objective of focussing on complying with or exceeding the benchmark.
- Dose estimates without reference to given benchmarks. If requirements do not have any benchmarks, the only specific objective can be to estimate realistic exposure values. Any approaches that deviate from this are purely speculative and should be considered unscientific.

The following requirements are derived from the purpose of estimating radiation exposure:

- Every dose estimate without reference to given values (limits, constraints or reference values) is only useful if it attempts to approximatively calculate the actual or potential radiation exposure of a person, or if it at least attempts to produce comparable results within a given framework ("calculation rule"). This leaves the approximation method and every conceivable form of result "precision" open-ended. However, basic requirements with regard to the result arise from the need to be able to reproduce the results and compare them with other values (not primarily with legally stipulated values). As a result, exposure estimates involving the general public can only be used if they permit (interpretable) comparisons with estimates involving members of the general public from other countries.
- If a dose estimate is to be used to check an existing or planned exposure situation for comparative values, it is often not necessary to approximately estimate the actual or potential radiation exposure to a person. Instead, it is sufficient to provide dose estimates for a situation in relation to the benchmark. This may be performed by means of a targeted overestimation ("conservative") and underestimation[8] ("restrictive") of the real exposure. If the dose estimate fulfils the purpose of the estimate, any other further reaching demands for accuracy or realism are contrary to the principle of proportionality.

In the following cases, realistic or more realistic dose estimates are required:

- If conservative estimates cannot prove compliance with limits or constraints with certainty.
- If in many individual cases (individual sources) that are not considered negligible, the exposure should be investigated in a cumulated manner and results checked for compliance with limits or constraints.
- If exposure to various sources should also be compared below the limit or trigger values.

However, these requirements fail to answer the question: "What is realistic and what is conservative?"

In this recommendation, the SSK takes realistic dose estimates to mean at least an approximate quantification of the actual or potential radiation exposure "as it is". In a metrological sense, radiation exposure is seen as an output quantity whose true value should be estimated as accurately as possible by performing measurements or through modelling.

The following points are to be distinguished from realistic dose estimation:

- Conservative dose estimate, i.e. a sufficiently accurate estimate that the actual or potential radiation exposure to a person or group of people is in fact low. Here, radiation exposure

[8] e.g. when investigating claims for damages by estimating minimum exposure values.

is seen as a unit whose true value is sufficiently certain to be below the value gleaned from the estimate;

- Restrictive dose estimate, which provides a sufficiently accurate estimate that the actual or potential radiation exposure to a person or group of people is in fact higher. Here, radiation exposure is seen as an output quantity whose true value is sufficiently certain to be above the value gleaned from the estimate.

Conservative (or restrictive) dose estimates can be achieved by

1) demanding or investigating high (or low) radiation exposure quantiles of probability distribution functions from probabilistic calculations,
2) choosing high (or low) quantiles of the input quantity values when using input quantities as point estimates in deterministic calculations,[9] or by
3) taking account of exposure pathways[10], behaviours, dietary habits, etc. which generally do not occur in practice.

An uncertainties analysis for conservative estimates is only possible in case 1).

Realistic radiation exposure estimates including an uncertainty analysis can be achieved by incorporating

1) probabilistic calculations with input quantity distributions,
2) deterministic calculations with best estimates of the input quantities and the standard uncertainties assigned to them, and
3) exposure pathways, behaviours, dietary habits, etc. which generally only occur in reality.

See Barthel and Thierfeldt (2012) for more information on the application of probabilistic and deterministic methods for dose estimation. Probabilistic methods offer the advantage of providing comprehensive information regarding probability distributions on the basis of the information available. However, deterministic methods with standard uncertainties as stipulated in GUM are first-order approximations which – if sufficient – also reflect the level of information available. An argument often put forward is that the data quality requirements are higher for probabilistic calculations than for deterministic calculations. This is incorrect, however, as both deterministic and probabilistic calculations can and should only reflect the respective level of information available.

3.4 Using modelling for dose estimations

This recommendation investigates realism requirements in terms of dose estimations on the basis of (radioecological) modelling. In general, radioecology is used to describe the behaviour of radionuclides and radiation fields in natural and technical human environments. This recommendation can be applied to every exposure situation which can be described by FEPs.

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9 It should be noted that this method is incorrect from a statistical perspective. Performing calculations with quantiles of a certain probability will not lead to any quantiles with the same probability. See Barthel and Thierfeldt (2012) for more information.

10 In practice, restrictive estimates only take account of essential exposure pathways, behaviours, dietary habits, etc.

An exposure scenario involves the natural and technical characteristics of the exposure situation as well as a set of processes and events that can influence human exposure to radiation.

This includes the reconstruction of past exposure, the determination of current exposure, and the prediction of future or potential exposure. Modelling may involve individuals, groups of employees, the general population, entire populations, or reference persons. The objectives of radioecological exposure assessments are as varied as their potential methodical approaches.

The task of radioecology is to always use models to estimate the dose to reference persons or real people from a certain radiation source in a certain exposure situation at any given location. To this end, the respective output quantity must be clearly defined in order to avoid misinterpretations when comparing different doses. It is of little importance whether the output quantity value of an exposure estimate is used for comparison with a limit, constraint or reference level or whether it is merely used as an indicator quantity, as is the case with long-term safety assessments, or for scientific analyses.

3.4.1 Dose quantities

By way of example and assuming universal applicability, radiation exposure shall be considered as effective dose E:

$$E = \sum_T w_T \sum_r w_r \cdot D_{r,T} \tag{4}$$

T	Index designating different tissue and organs
w_T	Tissue weighting factor for tissue or organ T
r	Index designating different radiation types
w_r	Radiation weighting factor for radiation type r
$D_{r,T}$	Dose absorbed by tissue T due to radiation type r

This definition includes the weighting factors w_T and w_r pursuant to ICRP (1991). No mention will be made here of the fact that the weighting factors w_T and w_r are variable for individuals rather than constant. In the convention of its definition according to equation (4), the effective dose is the output quantity used to investigate radiation exposures here. Due to the various different exposure pathways, the total effective dose

$$E_{\text{total}} = E_{\text{ext}} + E_{\text{inh}} + E_{\text{ing}} \tag{5}$$

is the sum of the externally effective dose E_{ext} and the effective doses from inhalation E_{inh} and from ingestion E_{ing}. For simplicity, additional exposure pathways such as absorption of radionuclides by the skin, direct ingestion of soil, and inhalation of dust are not considered here. The three summands for each radionuclide are each calculated as a product of several factors as set out in equations (6) to (8).

$$E_{\text{ext}} = \dot{E}_{\text{ext}} \cdot t_{\text{exp}} \tag{6}$$

$$E_{\text{inh}} = \sum_r A_{\text{V},r} \cdot \dot{V} \cdot t_{\text{exp}} \cdot g_{\text{inh},r} \tag{7}$$

$$E_{\text{ing}} = \sum_r A_{\text{m},r} \cdot \dot{U} \cdot t_{\text{exp}} \cdot g_{\text{ing},r} \tag{8}$$

$\dot{E}_{\mathrm{ext}}$ is the effective dose rate at the point of external exposure. A_{V} and A_{m} are the activity concentrations of a radionuclide in the matrix relevant to the exposure pathway; A_{V} is the activity concentration of the air while A_{m} is the activity concentration in foodstuffs. $\dot{V}$ and $\dot{U}$ are the breathing rates or the consumption rates of foodstuffs, respectively, and t_{exp} is the respective exposure time. The dose coefficients $g_{\mathrm{inh},r}$ for exposure by a radionuclide r due to inhalation in Sv Bq^{-1} and $g_{\mathrm{ing},r}$ for exposure due to ingestion in Sv Bq^{-1} depend on the nuclides and age and are parameters that have been stipulated by the ICRP (1996) and Euratom Basic Safety Standards. Effective doses have to be calculated separately for the various different age groups. For simplicity, equations (3) to (5) are used to represent the effective dose and apply to organ and tissue doses.

As radiation exposures are heavily dependent upon age and since the demographics of countries can differ greatly from one another, international comparisons are drawn pursuant to UNSCEAR (2000) by summarising age-dependent radiation exposures. In order to reflect the varying demographics, the summaries include a weighting that takes the frequency of age groups in that respective society into account by using

$$E_{\mathrm{total,mean}} = 0{,}05 \cdot E_{total,1<a\leq 2} + 0{,}30 \cdot E_{total,7<a\leq 12} + 0{,}65 \cdot E_{total,a>17} \quad (9)$$

as the mean. This does not correspond to the actual age distributions in Germany or other countries, but can be used as a convention for comparison purposes.

The definitions in equations (5) to (8) mean that radiation exposure for an individual is an output quantity with a well-defined true value.

3.4.2 Radioecological modelling

In many cases, radioecology describes the effects of radionuclide emissions and releases on humans and the environment, and to quantify radiation exposure by means of modelling. Model calculations must be performed and/or measurements taken on relevant environmental media to provide estimates in all cases where radiation exposure cannot be measured directly.

Creating the model is the most difficult part of solving the task, both in terms of general metrology and when it comes to dose estimates. This recommendation assumes there is a meaningful model in place that is in line with the state of the art in science and technology. Comparable situations addressing different aspects should be described by the same models. If simplified models are used as approximations, they should be distortion-free and unbiased and the approximations sufficient. Overarching models, i.e. models involving conservative overestimates, are sufficient in order to answer certain questions, but the SSK does not consider them to be suitable as realistic dose estimates.

Known exposure situations should be used to make sure the model reflects reality in as far as possible. A model that fails to describe natural circumstances or past experiences is not suitable for producing realistic dose exposure estimates.

In radioecological dose estimates, however, the actual individual values of the input quantities in equations (5) to (8) are not available in order to perform dose estimates, radioecological model calculations or measurements of suitable samples have to be performed in order to generate estimates. Figure 3.4 illustrates the complex paths that radionuclides take when passing from a source to humans.

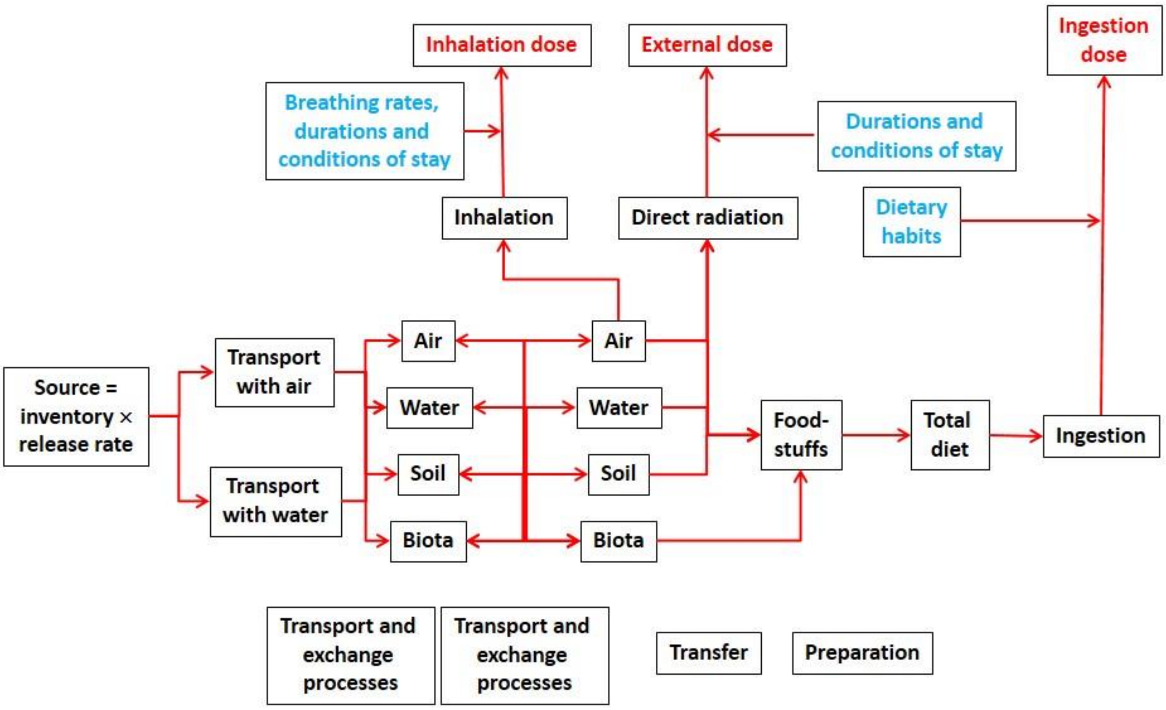

Fig. 3.4: Examples of pathways radionuclides take from a source through the environment to humans. As the chain of the transport and exchange processes may be both long and complex, they are shown twice and linked here.

The complexity but also the realism of the modelling depend on the information available about the source and radionuclides in the various environmental media (cf. Chapter 2.5.1).

3.4.3 Radiation exposure as a random quantity

In each case, radiation exposures are subject to various influences and dependencies with a high level of variability and are therefore random quantities whose true values have to be estimated using models.

Due to the variability of external dose rates and the activity concentrations in the relevant environmental media and living habits and behaviours, this applies not only to a group of individuals, but also to the probability of exposure to a single person. As a result, radiation exposure among a population or other group will exhibit distributions that retrospectively represent the actual differences in individual exposure, while also indicating the anticipated distributions of future or potential exposure.

Such distributions can be characterised by stating distribution parameters, e.g. of means, medians, modes, or expectation values. These parameters are distribution point estimates, and a single point estimate may only be used for full distribution characterisation in the event of a single-parameter Poisson distribution. With other multiparameter distributions, this is not sufficient. In fact it is not even certain whether radiation exposures are monomodal within a given population or whether they can be described by a single distribution.

This gives rise to the need for assumptions regarding the type of distributions and the fact that a sufficient number of parameters is required to fully characterise the distribution(s). Without further consideration of the respective distribution type, the point estimates mentioned above must be available and documented together with at least a sufficient number of distribution quantiles.

3.4.4 Quantifying uncertainty and variability

The quantification of uncertainties associated with an output quantity value has become essential in many areas of science. Uncertainties arise both from a lack of knowledge and information, and from the natural or anthropogenic variability of input quantities (see Barthel and Thierfeldt (2012) for more information).

In metrology, uncertainties are determined in a standardised way on the basis of international recommendations (JCGM 2008a, 2008b). In the case of measuring radiation in terms of dosimetry, monitoring radioactivity in the environment, and for clearance, uncertainties form the basis for estimating characteristic limits (decision thresholds and detection limits, limits of confidence or coverage intervals) and have become part of national and international legislation. In its 2005 recommendation "Principles and methods for consideration of statistical uncertainties in the determination of representative values of the specific activity of residues" (SSK 2005b), the SSK emphasised the importance of uncertainties.

Although the ICRP already emphasised the importance of uncertainties (cf. Chapter 3.2.4) in recommendation 60 (ICRP 1991) and again in recommendation 103 (ICRP 2007), so far no statements have been made with regard to uncertainties and variability when estimating radiation exposure in Germany. There is, however, a growing international trend towards quantifying uncertainties in both radiation protection and metrology. To this end, UNSCEAR is currently preparing a report on "Uncertainties in Risk Estimates for Cancer due to Exposure to Ionizing Radiation".

In conventional environmental protection and risk analysis, analyses of uncertainty are now standard practice (see Barthel and Thierfeldt (2012) for more information). As part of the International Programme on Chemical Safety (IPCS), the WHO drafted ten principles on characterising and assessing uncertainties for exposure estimates (WHO 2008):

"*Principle 1:* *Uncertainty analysis should be an integral part of exposure assessment.*

Principle 2: *The level of detail of the uncertainty analysis should be based on a tiered approach and consistent with the overall scope and purpose of the exposure and risk assessment.*

Principle 3: *Sources of uncertainty and variability should be systematically identified and evaluated in the exposure assessment.*

Principle 4: *The presence or absence of moderate to strong dependencies between model inputs is to be discussed and appropriately accounted for in the analysis.*

Principle 5: *Data, expert judgement or both should be used to inform the specification of uncertainties for scenarios, models and model parameters.*

Principle 6: *Sensitivity analysis should be an integral component of the uncertainty analysis in order to identify key sources of variability, uncertainty or both and to aid in iterative refinement of the exposure model. The results of sensitivity analysis should be used to identify key sources of uncertainty that should be the target of additional data collection or research, to identify key sources of controllable variability that can be the focus of risk management strategies and to evaluate model responses and the relative importance of various model inputs and model components to guide model development.*

Principle 7: *Uncertainty analyses for exposure assessment should be documented fully and systematically in a transparent manner, including both qualitative and* *quantitative aspects pertaining to data, methods, scenarios, inputs, models, outputs, sensitivity analysis and interpretation of results.*

Principle 8: *The uncertainty analysis should be subject to an evaluation process that may include peer review, model comparison, quality assurance or comparison with relevant data or independent observations.*

Principle 9: *Where appropriate to an assessment objective, exposure assessments should be iteratively refined over time to incorporate new data, information and methods to better characterise uncertainty and variability.*

Principle 10: *Communication of the results of exposure assessment uncertainties to the different stakeholders should reflect the different needs of the audiences in a transparent and understandable manner*".

The SSK holds the opinion that these principles should also be applied to radiation exposure estimates. The tools required to achieve this, e.g. JCGM 2008a, 2008b, already exist. Also see Barthel and Thierfeldt (2012) for more information.

The issue of realism of a dose estimate is closely related to the issue of the uncertainty of the result and of parameter variability. This should be discussed on the basis of the simple models set out in equations (3) to (5).

In accordance with a recommendation published by the WHO in 2008, the SSK considers it necessary to state the uncertainty associated with the result. The need to quantify uncertainties for dose estimates is based on ICRP 103 and the optimisation approach used there. Optimisation is generally not possible without the probabilistic method, i.e. the probability density function (PDF) of exposures.

Uncertainties should ideally be portrayed by a PDF rather than by stipulating best estimates and standard uncertainties. The PDF of the output quantities has to be determined in order to estimate output quantity quantiles. Deterministic calculations with quantiles do not produce quantiles as they are highly biased. Sensitivity analyses within the scope of uncertainty analyses enable the identification of parameters that are critical and for which detailed information has to be provided.

In various applications it has proven useful to distinguish between so-called epistemic and aleatoric uncertainties. Epistemic uncertainties are characterised by a lack of information and include measuring uncertainties, model uncertainties and a lack of knowledge. They can often be reduced by further efforts to acquire data and by performing further investigations. Aleatoric uncertainties are based on the natural or anthropogenic variability of input quantity values and parameters, and are the result of stochastic processes. Aleatoric uncertainties form part of the system and cannot be reduced by performing further investigations. See Barthel and Thierfeldt 2012 for more information on and further discussion of this point.

Separate handling of epistemic and aleatoric uncertainties in uncertainty and sensitivity analyses can often be useful. However, it is not necessary to distinguish between the two types[11] of uncertainty when it comes to the uncertainty to be assigned to the end result of a dose estimate as they are of equal value.

[11] Note that the designation of epistemic and aleatoric uncertainties as type A and type B as often seen in epidemiology does not correlate with the GUM categorisation of uncertainties into types A and B.

When it comes to dose estimation, there are three types of effective dose uncertainty that are of differing importance, namely:

- Model uncertainties,
- Measurement uncertainties and
- Parameter uncertainties.

Model uncertainties are the effects of simplifying model structures and approaches as well as of an extrapolation of models beyond the scope in which they were investigated empirically (e.g. including the specification of models for defined questions and situations).

Model uncertainties include uncertainties subject to the definition of dose quantities and are relevant to the tissue and radiation weighting factors in equation (1) and the dose coefficients in equations (3) to (5). In practice, these model uncertainties are generally irrelevant as the model parameters are stipulated by legislation. The models may indeed be flawed, but convention dictates that this model is to be used for dose estimates.

This means that w_T and w_r include uncertainties that are considered model uncertainties, but are defined as numerical values. Their uncertainties are therefore irrelevant for realistic dose estimates. There are, however, certain problems which justify the question of whether the effective dose in the form of equation (1) is a suitable quantity for describing radiation exposure. Such problems include the use of the effective dose to describe radiation exposure in medical diagnostics, the use of w_r pursuant to the Radiation Protection Ordinance (StrlSchV) for estimating special radiation fields such as radar devices with photon energies < 30 keV, and the indication of the committed effective dose for infants through to people aged up to 70 as the annual dose for infants of $\leq$ 1 year. The question of whether it makes sense to define an output quantity to describe the radiation exposure for an exposure situation or a certain aspect of radiation protection is not related to realistic exposure estimation. The question of whether the operational quantities represent suitable estimators for protection levels gives rise to the need for a model uncertainty.

For this recommendation it is of no importance whether the dose quantity to be considered also accounts for model uncertainties or whether legal requirements mean that individual parameters are used as point estimators without uncertainty for dose estimates. The question of whether such stipulations make sense are indeed very interesting from a scientific point of view and can be addressed time and again, but the social consensus considers it a fixed convention and therefore is not questioned here.

Model uncertainties are not dealt with in this recommendation, firstly due to normative stipulations (see above), and secondly because the model uncertainties are disregarded that occur when creating radioecological models for the pathways that radionuclides take from a source through the environment to humans. Model uncertainties are disregarded here because the the use of the best radioecological models based on the state of the art in science and technology as demanded by this recommendation ensures that a best-possible estimate will be made on the basis of available knowledge. This does not mean that model deficits, e.g. during validations, will not occur during the course of dose estimations. Any such deficits may indicate the need for research or improvements to the models.

In the given example, measuring uncertainties pursuant to GUM or GUM Supplement 1 (JGCM 2008a, 2008b) affect factors A_F, A_V and A_m. Measuring uncertainties are also usually irrelevant when it comes to the realism of dose estimates, but it may prove economically or technically difficult to perform measurements in the desired quality. Measuring uncertainties are, however, only one source of variability of the factors A_F, A_V and A_m. They are also uncertain as a result of variability of the ecological processes to be expected together with the following parameter uncertainties. A_F, A_V and A_m are random variables of physical quantities which have a well-defined true value for a certain sample. This is no longer the case for different samples when multiple samples of a material are tested randomly.

Parameter uncertainties are the result of the natural and anthropogenic variability of quantities that influence or are used for dose estimates. Various uncertain parameters have a multiplicative impact on radiation exposure and are both the main cause of uncertainty of radioecological dose estimates and the main reason behind the need for realistic dose estimates. In equations (3) to (5), this includes A_F, A_V and A_m. As these quantities are random variables, radiation exposure is therefore also a random quantity.

Parameter uncertainties give rise to the following statement: The true value of an individual's exposure to radiation is the actual value of a random quantity to be determined by the actual values of many other random quantities.

Three conclusions can be drawn from this statement:

– According to a given definition of the dose, radiation exposure for an individual is an output quantity with a well-defined true value. The true value is fundamentally unknown and has to be estimated by means of measurements and model calculations.
– Parameter variability means that this does not apply to a group of individuals. A group exhibits a distribution of the true individual exposure values to be estimated by radioecology methods.
– For an individual in a certain situation, effective dose E is an output quantity with a clearly fixed true value to be determined. Effective dose E is not an output quantity for a group of individuals under the "same conditions" since varying exposures are to be expected among the different members of the group due to the random variability of the quantities that influence exposure, and exposure therefore needs to be described by a probability distribution for the true value.

This in turn means that realistic dose estimates for a group or population can only be provided by estimating the distribution of individual doses, either by measuring individual doses or by estimating the probability distribution of the individual doses.

Radiation exposures estimated in that way can be characterised by stipulating distribution parameters, e.g. of means, medians, modes, or expectation values. These parameters are distribution point estimates, and a single point estimate may only be used for full distribution characterisation in the event of a single-parameter Poisson distribution. With multiparameter distributions, this is not sufficient. In fact it is not even certain whether radiation exposures are monomodal within a given population or whether they can be described by a single distribution.

This gives rise to the need for assumptions regarding the type of distributions and the fact that a sufficient number of parameters is required to fully characterise the distribution(s). Without further consideration of the respective distribution type, the above point estimates must be available and documented together with at least a sufficient number of distribution quantiles.

There are also cases where point estimates are sufficient. In radiation hygiene, the expected value of radiation exposure may be used as a meaningful point estimate of risk in a population based on the linear no-threshold (LNT) hypothesis. This does not apply, however, to medians, means or attributive risk estimates.

The above also applies in medicine, where the dose absorbed by a tissue or an organ in a group of patients is governed by a distribution of $D_{r,T}$ which represents an output quantity with a true value for each individual patient. However, the observed or estimated distribution of $D_{r,T}$ differs from the distribution of effective doses because, in general medicine, an irregular age distribution and w_T to be stipulated specifically both have an impact on the distribution of absorbed doses.

The same formulae apply to realistic and conservative calculations. Then the question is “What is realistic dose estimation?” The answer to that is “The true value should be estimated as accurately as possible by performing measurements or through modelling.”

3.5 Realistic dose estimation

Within the context of this recommendation, realistic dose estimation means to provide as accurate an estimate of the true output quantity value as possible based on the information available, and to quantify its uncertainty. This involves two aspects. Firstly, the avoidance of overestimates (conservatism) and underestimates. Secondly, the uncertainty should be kept as small as possible by taking account of all sources of uncertainty. Estimates of radiation exposure are the more realistic the less they over- or underestimate the dose and the smaller the uncertainty is.

The term realism often leads to some confusion as in everyday language it is also understood to convey the sense of a quality, i.e. less realistic is bad and imprecise, while realistic is good and precise. Within the scope of this recommendation, realism is taken to mean a best estimate based on the information available. In contrast, conservatism is taken to mean a targeted overestimate.

3.5.1 Recommendation methodology

If radiation exposure is seen as an output quantity whose true value is to be estimated on the basis of the information available, it is irrelevant whether it involves an expected or past radiation exposure, or a residual or averted dose. The question whether the quantity of interest is an effective dose or an organ doses does not affect the methodology of realistic exposure estimates. In any case, however, the respective output quantity must be clearly defined (cf. Chapter 2).

Output quantities of interest could be:

- Dose to a reference person at the most unfavourable receiving points (ubiquity),
- Dose to a reference person at the most unfavourable receiving point (representative reference person or most exposed individual),
- Dose to the most exposed person (representative person or most exposed individual),
- Dose to a reference person at a given location,
- Dose to a real person at a given location,
- Dose to a critical group of real persons or reference persons (the latter: representative reference persons),
- Dose to people exposed in an exposure situation,
- Dose distribution among an entire population.

The method can be represented by a general statement, namely that the dose to any person at an arbitrary location at any given time needs to be estimated for every relevant exposure pathway.

The assessment model design linking the input quantities with the output quantities forms the basis for each output quantity and dose. The model equations for the various dose estimate variants may vary by means of radioecological methods as set out below in relation to the available information, but they still describe the same radioecology. This is why the SSK recommends only using a single radioecological model within the sense of a best practice. In each case, the respective output quantity, assessment model, and model assumptions must be documented in full.

Further, the values of the output quantity to be determined also have to be specified: the PDF of the true values of the output quantity, a coverage interval or a high quantile for given probabilities, or the best estimate with its associated uncertainty. In this SSK recommendation, overarching point estimates are only deemed acceptable for use as a target quantity in the event of licencing procedures involving calculations pursuant to the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV).

Two key factors determine the potential level of realism for dose estimates, namely the model chosen based on the information available about the source, and the exposure situation which includes the scenarios and exposure pathways, radioecological model parameters and human parameters used for modelling. Table 3.3 summarises the potential modelling categories I0 → I4.

Table 3.3: Categorisation of dose estimates based on the available information (information categorisation).

Category	Available information
I0	From a overarching hypothetical source term
I1	From a hypothetical source term (best estimate based on predictions)
I2	From an actual source term (best estimate based on measured data)
I3	From the measured ambient dose rate and activity concentrations in foodstuffs modelled from data measured for the air, soil and water
I4	From measured activity concentrations in the air, soil, water, foodstuffs, ambient dose rate as well as dosimeters, whole-body measurements, bioassay, etc.

The opportunity for realistic dose estimation rises from I0 to I4. The more information is available, the more realistic radiation exposure estimates for the general public will be. The longer the model chain that needs to be modelled, the greater the uncertainties of the dose estimate will become.

Four levels of realism with the situation categories S0 to S4 can be distinguished for modelling exposure situations. These depend on whether overarching (also impossible) assumptions, generic data, case-specific data or individual data relating to a cohort or real critical group are used for the scenarios and exposure pathways, radioecological model parameters and human parameters. Here, data means best estimates together with their uncertainties or PDFs. PDF quantiles are unsuitable as input values because calculations involving quantiles will not result in quantiles.

When estimating exposure, the scenarios and exposure paths, radioecological model parameters and human parameters resulting from the FEPs are used as input quantities whose realism also depends upon the information available. Table 3.4 shows a system with 4 levels for FEPs, scenarios and exposure paths, radioecological model parameters and human parameters. The input quantity values range from overarching and impossible (S0), potential and generic (S1), case-specific and real (S2), through to case-specific and individual data (S3). Dose estimates are most realistic for S3 and least realistic for S0. The transition from S0 to S1 sees the removal of overestimates (conservatisms), while the transition from S1 to S3 sees the removal of uncertainties.

Table 3.4: Categorisation of exposure situations (situation categories).

	Situation categories			
	S0	**S1**	**S2**	**S3**
FEPs, scenarios and exposure pathways	Overarching (also impossible); e.g. equilibrium condition (50 a), ubiquity, implausible consumption quantities	Only realistically and legally feasible; generic; disequilibria	Real case-specifically existing; disequilibria	Real case-specifically existing and legally feasible; individual data of a cohort; disequilibria
Radioecological model parameters*	Generic 95th percentile	Generic data	Case-specific data	Case-specific data
Dietary habits	Generic data, either overarching or 95th percentile	Generic data	Case-specific data	Individual data
Durations of stay	permanent stay	Generic data	Case-specific data	Individual data
Percentage of locally produced foodstuffs	100%	Generic data	Case-specific data	Individual data

* e.g. K_d levels, transfer factors, solubilities, etc.

Figures 3.5 to 3.9 illustrate the combinations of information categories and situation categories deemed useful in this recommendation in order to highlight the differences in terms of the information available.

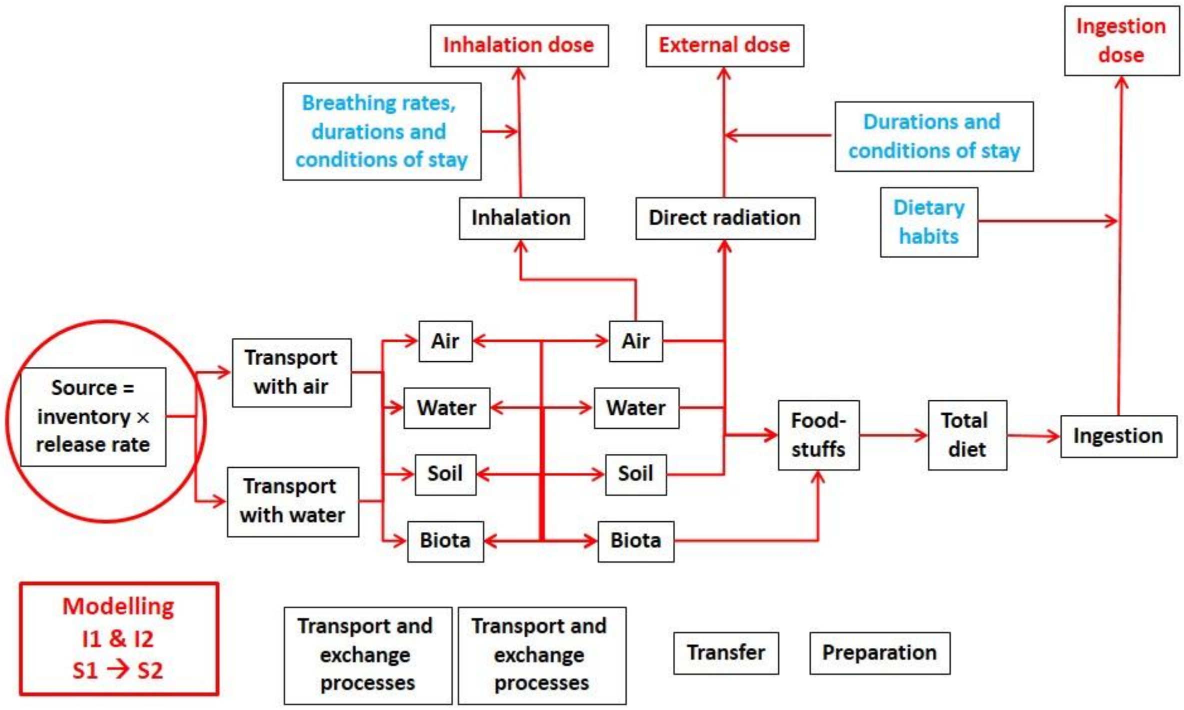

Fig. 3.5: Radiation exposure modelling from a source term with case-specific data relating to conditions of stay and consumption rates (I1 & I2; S1 → S2).

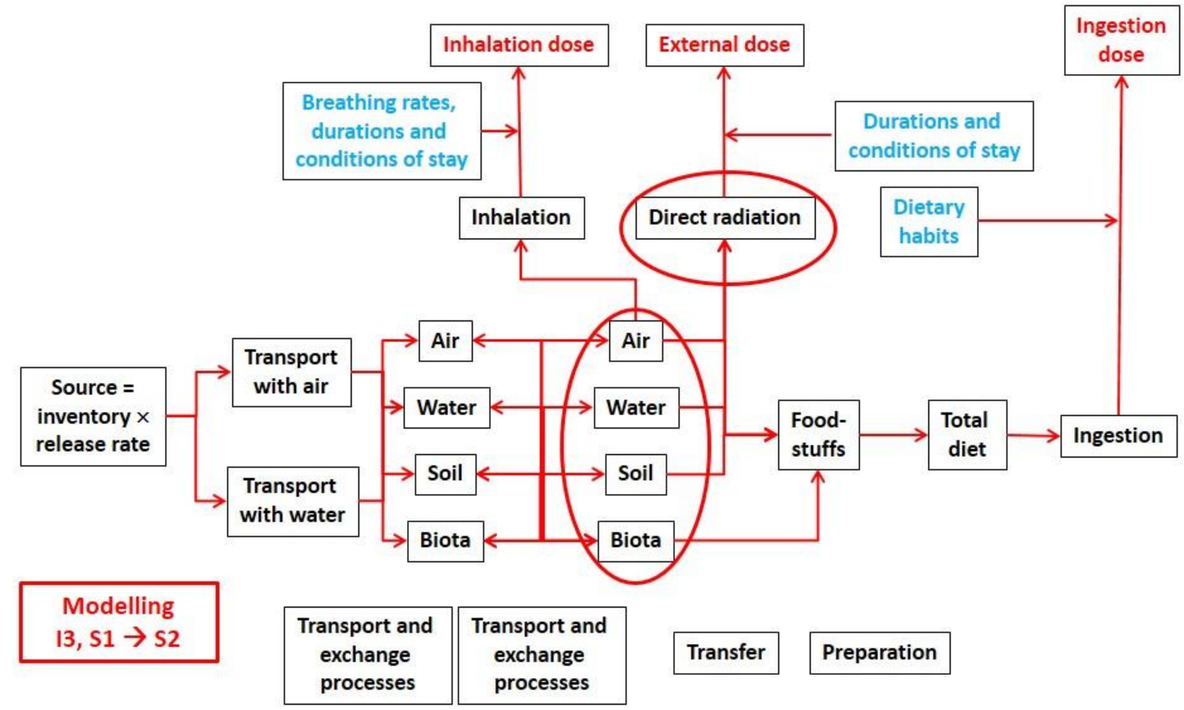

Fig. 3.6: Radiation exposure modelling from activity concentrations in foodstuffs and ambient dose rates calculated from data for the soil, air and water (I3; S1 → S2).

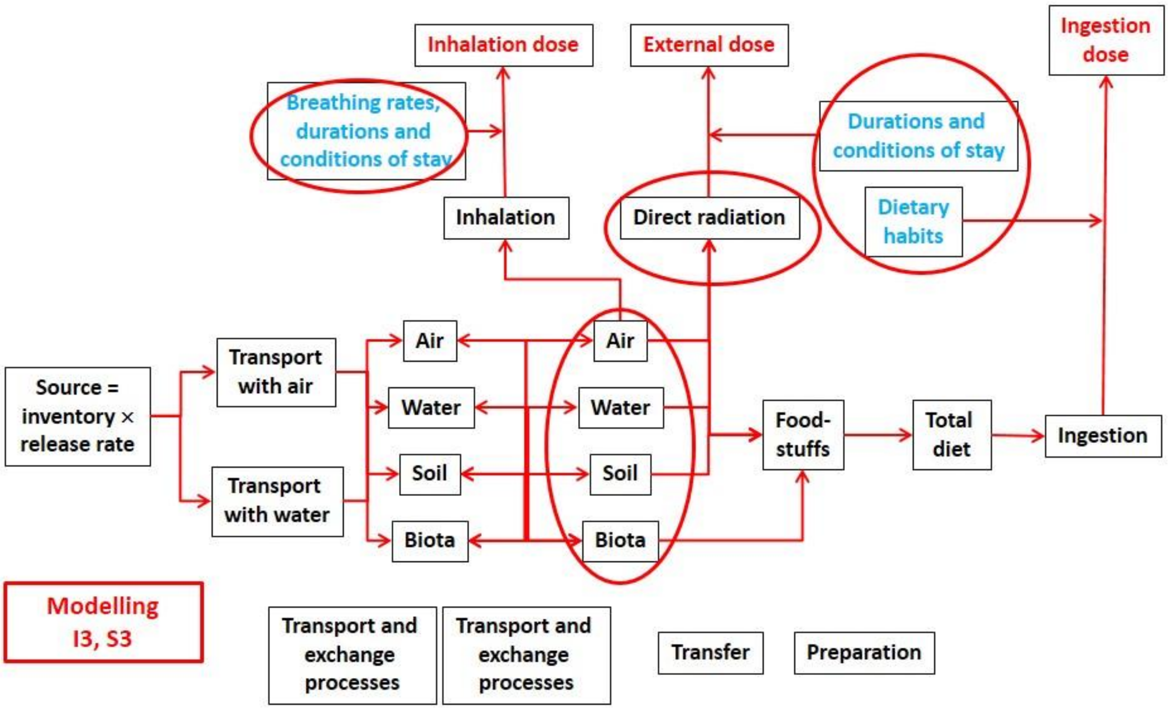

Fig. 3.7: Radiation exposure modelling from activity concentrations in foodstuffs and ambient dose rate calculated from data for the soil, air and water (I3; S3).

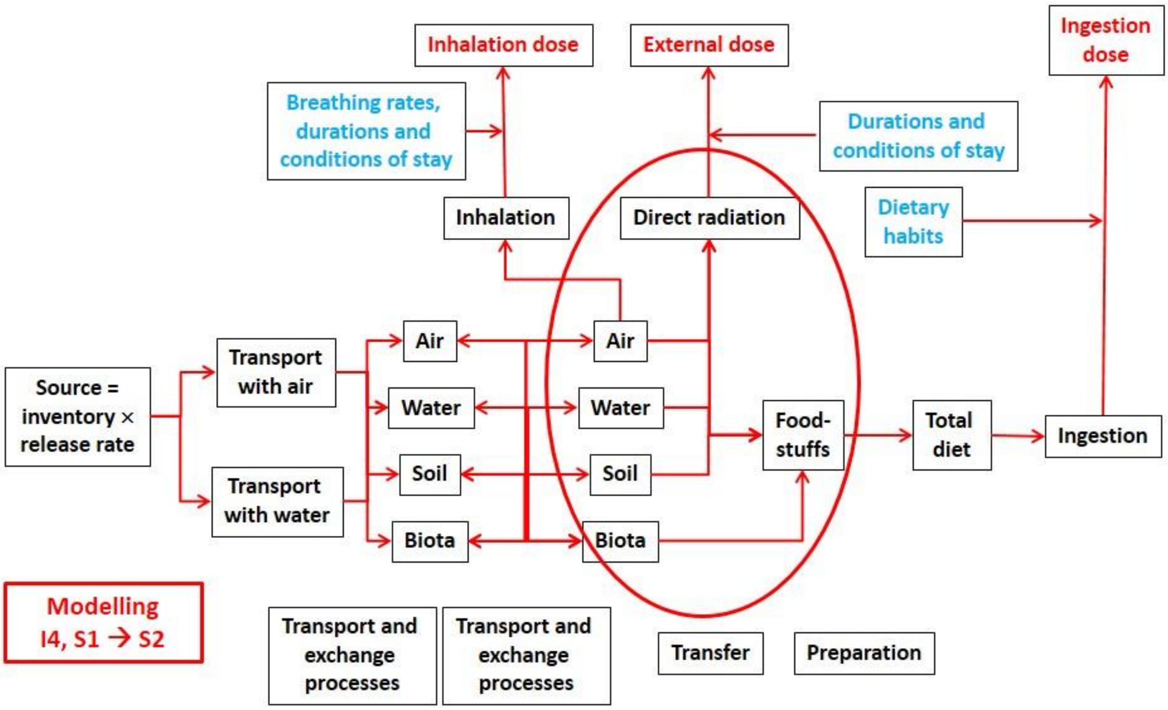

Fig. 3.8: Radiation exposure modelling from measured activity concentrations in the air, soil, water, foodstuffs, ambient dose rate (as well as dosimeters, whole-body measurements, and bioassay) with generic data about conditions of stay and consumption quantities (I4; S1 → S2).

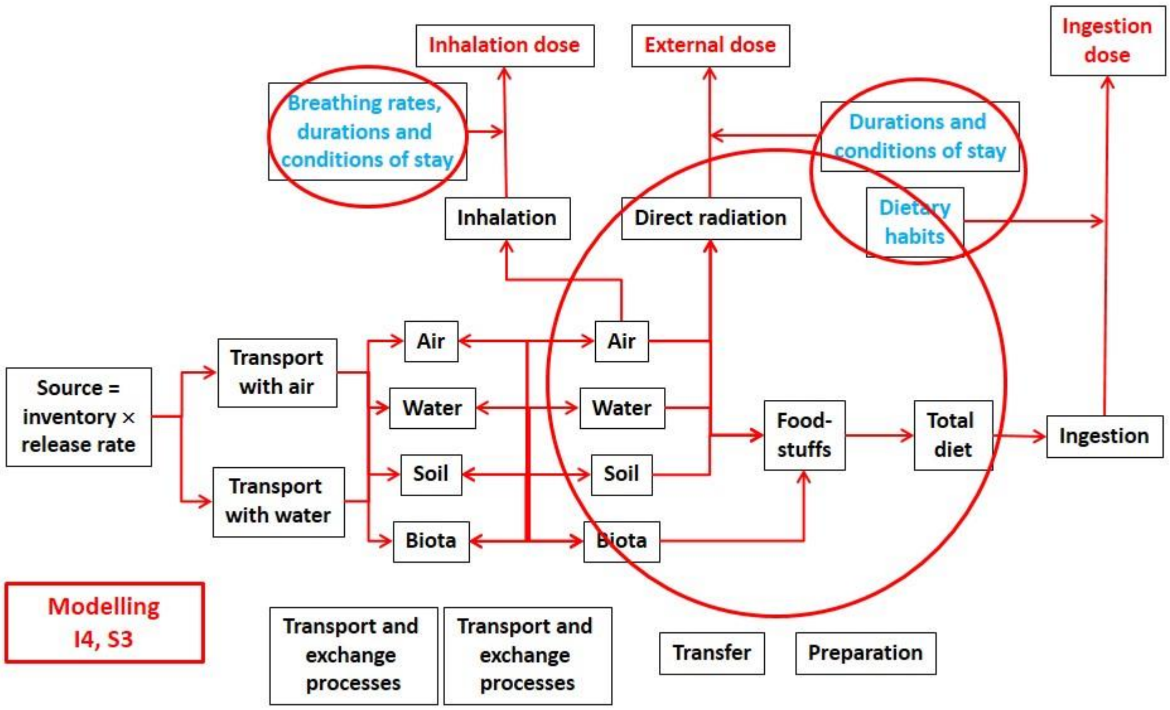

Fig. 3.9: Radiation exposure modelling from measured activity concentrations in the air, soil, water, foodstuffs, ambient dose rate (as well as dosimeters, whole-body measurements, and bioassay) with individual data about conditions of stay and consumption quantities (I4; S3).

In general, the various combinations of information categories and levels of scenarios and exposure pathways, radioecological model parameters, FEPs and human parameters do not lead to the same results and have varying uncertainties. Experience shows, however, that the more information available and the shorter the model chain, the more realistic, i.e. reliable, the results will be.

The available information determines the information category. FEPs, scenarios and exposure paths, radioecological model parameters and human parameters should determine the situation category as realistically as possible. The level of modelling realism is determined by combining an information category with a situation category. The realism of dose estimates increases with the information categories (I1 < I2 < I3 < I4) and with the situation categories (S0 < S1 < S2 < S3). Table 3.5 shows the level of realism by means of colour coding where red means unrealistic and green means realistic.

The Euratom Basic Safety Standards require radiation exposure from practices to be estimated as realistically as possible. In table 3.5 this means striving to end up in the bottom right-hand corner with a reasonable amount of work.

Table 3.5: Categorisation of potential dose estimates.

Situation category / **Information category**	**S0** Overarching (also impossible); e.g. equilibrium condition (50 a), ubiquity, implausible consumption quantities	**S1** Only realistically and legally feasible; generic; disequilibria	**S2** Real case-specifically existing and legally feasible; disequilibria	**S3** Real case-specifically existing and legally feasible; individual data of a cohort; disequilibria
I0 From a overarching hypothetical source term				
I1 From a hypothetical source				
I2 From an actual source				
I3 Data for the soil, air, water, ambient dose rate, and water				
I4 Data for the soil, air, water, foodstuffs, ambient dose rate as well as dosimeter, whole-body measurement, bioassay, etc.				

It is only partially the decision of the user how much information is available for a particular case. It often depends simply on the options the user has access or to obtain the desired information. The amount of effort potentially required and available resources also influence the level of information available.

Based on the classification of exposure situations in ICRP 103 as planned, existing or emergency exposure situations, and taking account of the fact that retrospective and prospective dose estimates will always have varying levels of information available, the SSK recommends performing radioecological dose estimates based on the model set out in tables 3.6 and 3.7.

Table 3.6: SSK recommendation for assigning application scopes to dose estimate categories.

Situation category / Information category	**S0** Overarching (also impossible); e.g. equilibrium condition (50 a), ubiquity, implausible consumption quantities	**S1** Only realistically and legally feasible; generic; disequilibria	**S2** Real case-specifically existing and legally feasible; disequilibria	**S3** Real case-specifically existing and legally feasible; individual data of a cohort; disequilibria
I0 From a overarching hypothetical source term	Prospectively in planned situations in licencing procedures involving the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV)			
I1 From a hypothetical source		Prospectively in emergency exposure situations and other* planned exposure situations	Prospectively in other* planned exposure situations	
I2 From an actual source		Retrospectively and prospectively in planned, existing and emergency exposure situations	Retrospectively and prospectively in planned, existing and emergency exposure situations	
I3 Data for the soil, air, water, ambient dose rate, and water		Retrospectively and prospectively in existing and emergency exposure situations	Retrospectively and prospectively in existing and emergency exposure situations	Retrospectively in existing and emergency exposure situations
I4 Data for the air, soil, water, foodstuffs, ambient dose rate as well as dosimeter, whole-body measurement, bioassay, etc.		Retrospectively and prospectively in existing and emergency exposure situations	Retrospectively and prospectively in existing and emergency exposure situations	Retrospectively for cohorts in existing and emergency exposure situations

*Exposure situations not subject to authorisation as stipulated in § 47 of the Radiation Protection Ordinance (StrlSchV).

The SSK only considers situation category S0 to be of use in the case of the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV). In all other exposure situations, S1 and, where possible, S2 should be used. S3 should be reserved for investigating cohorts involving real critical groups. As long as unbiased methods are used, the SSK considers a tiered dose estimation approach sufficient with regard to meeting the Euratom Basic Safety Standards requirement. The various tiers may be based on the level of information available, meaning that a varying amount of information gathering work may be required. The goal is to make estimates “as realistic as possible”. In table 3.5 this means striving to end up in the bottom right-hand corner with a reasonable amount of work.

Table 3.7: SSK recommendation for realistic dose estimates.

	Prospectively		**Retrospectively**	
Planned exposure situations: Licencing procedures involving the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV)	I0	S0	I2	S1 → S2
Other planned exposure situations, e.g. final nuclear waste repositories and contaminated sites	I1	S1 → S2	I2 → I4	S1 → S2
Emergency exposure situations	I1 → I4	S1 → S2	I3 → I4	S1 → S3
Existing exposure situations	I3 → I4	S1 → S2	I3 → I4	S1 → S3

Long-term forecasts pose a particular problem when considering final nuclear waste repositories and contaminated sites. Here, potential radiation exposure cannot be realistically estimated because it is not possible to reliably predict conditions in the distant future. The potential dose estimates for long-term assessments of final nuclear waste repositories and contaminated sites only constitute indicator values within the scope of long-term safety assessment considerations. The variability of potential radiation exposures in the distant future can only be mapped by varying the potential FEPs and exposure scenarios. Estimations for each individual FEP and scenario should be carried out as realistically as possible in order to compare the potential radiation exposures resulting from the various FEPs and exposure scenarios with the aim of optimising the planned measures.

A clear position in the matrix of information categories and levels of scenarios and exposure pathways, radioecological model parameters, FEPs and human parameters can be assigned to the various application scopes. In this sense, a tiered approach with simpler modelling that involves less work and information about scenarios and exposure pathways, radioecological model parameters, FEPs and human parameters can be used for non-relevant exposure situations, while greater efforts should be made when considering more relevant exposures.

As already mentioned, a single radioecological model with a best practice should be used for the same application scopes. That way, all of the combinations of information categories and levels of scenarios and exposure pathways, radioecological model parameters, FEPs and human parameters (except for I0, S0) can be deemed realistic. To do so, the available information must be used as set out in GUM or GUM Supplement 1 in order to obtain a best estimate of the dose and its accompanying uncertainty.

The SSK considers it essential to quantify uncertainties for dose estimates.Waiving of uncertainty quantification should only be tolerated in the event of the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) and the Basis of Estimation for Incidents SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV). In these cases, just extremely conservative estimates are made and it is rarely possible to quantify uncertainties as sometimes high quantiles of input quantities are use as input values. To recap, performing calculations with quantiles will not produce any quantiles.

In all other application scopes, uncertainties can be determined using international standards. The abbreviations GUM or GUM Supplement 1 are used below for the standards pursuant to JCGM 2008a and JCGM 2008b. As radiation exposure is a multifactorial event, the multiplicative central limiting theorem of statistics dictates that radionuclide concentrations in environmental media and general radiation exposures conform to logarithmic normal distributions. The gold standard of uncertainty analysis is the complete calculation of a probability distribution density (PDF) or of a probability function for a given exposure situation. According to GUM, standard uncertainties are only appropriate in simple measuring situations. Probabilistic methods pursuant to GUM Supplement 1 generally only allow for the calculation of the PDF of the dose. The recommended requirements in terms of quantifying uncertainties based on GUM are indicated by “u(D)”, while the recommended requirements in terms of quantifying uncertainties based on GUM Supplement 1 are indicated through the stipulation of the PDF or the probability function.

Particular attention should be paid to situations in which the uncertainty of individual input quantities dominates the uncertainty of the output quantity or in which relevant information about individual input quantities is not available. Here, an uncertainty analysis can help to determine where more work is necessary to obtain the required information. This is highly critical in questions of final storage where uncertainties relating to future time projections coincide with a lack of knowledge surrounding geological formations and parameters. Here, possibilistic methods or 3D Monte Carlo simulations may be of use.

It should be noted that there are conventional parameters as input quantities for which uncertainties are not taken into account. These include, for example, dose coefficients, other quantities set out in the legislation, and possible other quantities such as dispersion factors and conservative calibration factors

The importance of modelling consistency in the various information categories should also be pointed out. Here, the principle mentioned above can be used as an evaluation method: A model that fails to describe natural circumstances or past experiences is not suitable for producing realistic dose estimates.

To conclude, documentation containing clear stipulations of output quantities, models, scenarios and exposure pathways, and parameters is required in each case as this is the only way to ensure comparability. Table 3.8 below can be used to clearly describe the respective dose estimate. In the following chapter, the SSK will provide full documentation for the various dose estimate applications.

Table 3.8: Template in dose estimates in various application scenarios.

Exposure situation, application, purpose	
Output quantity and values to be calculated	
Exposure modelling (I0 – I4)	
Scenarios and exposure pathways (S0 – S3)	
Radioecological model parameters (S0 – S3)	
Dietary habits (S0 – S3)	
Durations of stay (S0 – S3)	
Percentage of locally produced foodstuffs (S0 – S3)	
Uncertainties: (GUM, GUM Suppl. 1)	

3.5.2 Example applications

As per the advisory mandate from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the method stated can be used as a basis for identifying and determining situations where a realistic calculation of radiation exposure would be necessary or useful by using the table 3.8.

The determination of models, model parameters and model quantities to be used realistically with identified situations would be beyond the scope of this recommendation and should therefore be decided during the development or further development of the calculation guides.

The SSK does not recommend a fundamental change to the models used in current legislation, even if clarification of the models and model hierarchies would be desirable in the event of questions relating to the long-term safety of final nuclear waste repositories and contaminated sites. In the light of experiences in connection with the Fukushima Daiichi reactor accident, the forecast models and assumptions used within the scope of emergency protection need to be subjected to a critical evaluation. From a more general point of view, the adaption of the radiation protection system to the exposure situations based on ICRP 103 will require revisions to the previously used models, particular with regard to the practical design of optimisation.

The models used should be in line with the state of the art in science and technology. For this reason, a critical evaluation should be performed on a regular basis. The validation of models for new exposure situations and experiences is essential.

With any model which describes an exposure situation according to the state of the art in science and technology both conservative/restrictive and realistic dose estimations can be performed. This is why the various applications are dealt with individually in terms of the realistic estimate requirements.

Table 3.9: ***Applications I.1 – I.3:*** *SSK proposal on reporting natural radiation exposure and exposure due to global fallout from atmospheric nuclear weapons explosions and the Chernobyl accident to the parliament, the EU and UNSCEAR.*

Application	**Existing exposure situation, retrospectively**
Output quantity and values to be calculated	Dose to reference persons from the general public for reporting purposes; UNSCEAR convention: best estimate with PDF
Exposure modelling	I3 → I4: From the ambient dose rate and activity concentrations in the air, soil, water, foodstuffs and dosimetry
Scenarios and exposure pathways	S1: All realistically and legally feasible; generic; disequilibria
Radioecological model parameters	S1: Generic mean values and uncertainties
Consumption habits	S1: Generic mean values and uncertainties
Durations of stay	S1: Generic mean values and uncertainties
Percentage of locally produced foodstuffs	S1: Generic mean values and uncertainties
Uncertainties	In the event of natural radiation exposure and exposure due to the Chernobyl accident as per GUM Supplement 1, and in the event of global fallout, uncertainties pursuant to GUM are sufficient.

Reporting natural radiation exposure to the parliament, the EU and UNSCEAR represents the general case of retrospective dose estimation for an existing exposure situation. Here, the reference group of the population under consideration is the German population or that of individual German states (Länder). Comprehensive historical and current data are available about environmental radioactivity, including activity of the body. When considered on an international level, previous deterministic estimates that do not quantify the uncertainties may be considered validated on the basis of a wide range of scientific publications.

Until now, the Federal Republic of Germany is not one of the group of countries to have reported a dose distribution of natural radiation exposure to UNSCEAR. According to the UNSCEAR (2000) report, 10 countries reported their dose distribution of natural radiation exposure. The SSK recommends performing an uncertainty analysis with probabilistic methods based on GUM Supplement 1 to estimate natural radiation exposure and exposure due to the Chernobyl accident. See Barthel and Thierfeldt (2012) for more information about probabilistic methods. Valbruch (2004) presents a first probabilistic estimate for natural radiation exposure.

The SSK recommends proceeding as per table 3.9 when reporting natural radiation exposure and exposure due to global fallout from atmospheric nuclear weapons explosions and the Chernobyl accident to the parliament, the EU and UNSCEAR.

Table 3.10 shows the current process for reporting radiation exposure due to discharge from nuclear facilities and installations during normal operation. The SSK considers this process to be unacceptable (cf. also Chapter 3.2.5). Even, if the doses to reference persons at the most unfavourable receiving points are far below the dose limits, they are of major political importance. Realism is what is required here.

*Table 3.10: **Application I.4-1:** Current procedures of reporting radiation exposure from nuclear facilities and installations to the parliament and the EU.*

Application	**Planned exposure situation, retrospectively: Art. 45 EU**
Output quantity and values to be calculated	Dose to a reference person at the most unfavourable receiving points (ubiquity); overarching point estimates
Exposure modelling	I2: From actual source term with actual weather
Scenarios and exposure pathways	S0: overarching (also impossible), equilibrium
Radioecological model parameters	S1: Generic mean values
Consumption habits	S0: Generic 95th percentile
Durations of stay	S0: permanent stay
Percentage of locally produced foodstuffs	S0: 100%
Uncertainties	None

In addition, doses to reference persons at the most unfavourable receiving points are not seen to be representative of radiation exposure to the general public in the vicinity of nuclear facilities and installations. A clear distinction of doses for most exposed individuals of the general public and other reference groups of the population is required.

Therefore, the SSK proposes a change to the previous procedure as set out in table 3.11. The SSK sees an urgent need to quantify uncertainties and variability, ideally in the form of distributions.

Given the current unsatisfactory situation, the Federal Office for Radiation Protection (BfS) proposed a tiered reporting concept (BfS 2009a). The SSK considers this to be insufficient and only partially suitable for implementing the realism requirement set out in the Euratom Basic Safety Standards.

*Table 3.11: **Application I.4-1:** SSK proposal for the reporting of radiation exposure from nuclear facilities and installations to the parliament and the EU.*

Application	**Planned exposure situation, retrospectively: Art. 45 EU**
Output quantity and values to be calculated	Dose to reference persons at the most unfavourable receiving point (representative reference person or MEI=most exposed individual). Best estimate with uncertainty or PDF. Mean dose to reference persons of the general public within a 5 km radius with uncertainties. Mean dose to reference persons in Germany with uncertainties.
Exposure modelling	I2: From actual source term with actual weather
Scenarios and exposure pathways	S2: Case-specific existing and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S2: Location-specific mean values and uncertainties
Consumption habits	S1: Generic mean values and uncertainties
Durations of stay	S1: Generic mean values and uncertainties
Percentage of locally produced foodstuffs	S2: Case-specific mean values and uncertainties
Uncertainties	GUM or GUM Supplement 1

The estimation of radiation exposure among the general public in the wake of incidents and accidents is of major political, societal and scientific importance. Real reference groups of the population need to be identified and their radiation exposure estimated. On top of that, exposures to larger reference groups of the population in the near vicinity need to be retrospectively estimated as realistically as possible. This also means incorporating as much case-specific information as possible. As long as the circumstances do not require the formation of a cohort for a cohort study (cf. Application I.5-1), the use of generic human characteristics is sufficient.

When estimating radiation exposure in the wake of incidents and accidents, there is a smooth transition to the requirements for epidemiological studies. In the event of an incident, requirements must be prudently determined by accounting for radioecological and economical aspects as well as political and societal circumstances in each individual case.

*Table 3.12: **Application I.4-2:** SSK proposal for estimating radiation exposure among members of the general public resulting from practices after incidents and accidents.*

Application	**Existing exposure situation, retrospectively: Radiation exposure after incidents and accidents**
Output quantity and values to be calculated	Dose to representative reference persons at the most unfavourable receiving point (most exposed individuals). Best estimate with uncertainty or PDF Mean dose to reference persons of the affected population including dose distribution
Exposure modelling	I2 → I4: Based on available information about the actual source term and weather as well as environmental radioactivity and dosimetry data
Scenarios and exposure pathways	S2: Case-specific existing and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S2: Case-specific mean values and uncertainties
Consumption habits	S1: Generic mean values and uncertainties
Durations of stay	S1 → S2: Generic mean values and uncertainties or data collected about affected persons
Percentage of locally produced foodstuffs	S2: Case-specific mean values and uncertainties
Uncertainties	GUM Supplement 1

The realistic dose estimate requirements for epidemiological research stem from the characteristics of the various different epidemiological studies: cohort and case-control studies. The principle here will be to always use all of the available information when modelling exposure, both for estimation and validation purposes (category I4).

As study participants are known in cohort and case-control studies, individual data may be used for human parameters (table 3.13). Examples here include the cohorts for the life span study and currently recruited Fukushima Cohorts.

As the individuals involved in ecological studies are unknown, only generic or, at best, case-specific data can be used here (table 3.14). Here the same radiation exposure estimate requirements should be laid down as those used to estimate radiation exposure in Tokyo and Ibaraki prefecture after the Fukushima Daiichi reactor accident as well as to estimate radiation exposure among populations in countries that are further away, e.g. Germany, after the Chernobyl nuclear accident.

Table 3.13: ***Application I.5-1:*** *SSK proposal for epidemiological research; cohort and case-control studies.*

Application	**Existing and emergency exposure situation, retrospectively: Epidemiology**
Output quantity and values to be calculated	Dose to a reference person at a single location: best estimate with uncertainty or PDF
Exposure modelling	I4: From measured activity concentrations in the air, soil, water, foodstuffs, ambient dose rate (as well as dosimeters, whole-body measurements, and bioassay)
Scenarios and exposure pathways	S3: All realistically and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S3: Case-specific mean values and uncertainties
Consumption habits	S3: Individual data and uncertainties
Durations of stay	S3: Individual data and uncertainties
Percentage of locally produced foodstuffs	S3: Individual data and uncertainties
Uncertainties	GUM Supplement 1

Table 3.14: ***Application I.5-2:*** *SSK proposal for epidemiological research: ecological studies for an existing exposure situation, retrospectively or prospectively: Reporting*

Application	**Existing exposure situation, retrospectively or prospectively: Reporting**
Output quantity and values to be calculated	Dose to a reference person at a single location: best estimate with uncertainty or PDF
Exposure modelling	I4: From measured activity concentrations in the air, soil, water, foodstuffs, ambient dose rate (as well as dosimeters, whole-body measurements, and bioassay)
Scenarios and exposure pathways	S1 → S2: All realistically and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases, case-specific where available
Radioecological model parameters	S1 → S2: Generic mean values and uncertainties, case-specific where available
Consumption habits	S1 → S2: Generic mean values and uncertainties, case-specific where available
Durations of stay	S1 → S2: Generic mean values and uncertainties, case-specific where available
Percentage of locally produced foodstuffs	S1 → S2: Generic mean values and uncertainties, case-specific where available
Uncertainties	GUM Supplement 1

In more heavily affected regions such as the Fukushima prefecture in Japan, dose estimates are required that extend beyond the general requirements of ecological studies both for reporting purposes and, more importantly, for remediation measures in order to optimise radiation protection. These requirements are described below in Table 3.15.

Table 3.15: ***Application I.5-2:*** *SSK proposal for epidemiological research: ecological studies for an existing or emergency exposure situation, prospectively.*

Application	**Existing or emergency exposure situation, prospectively**
Output quantity and values to be calculated	Dose to a reference person at a single location for optimisation purposes: Dose distribution required, best estimate with uncertainty or PDF
Exposure modelling	I4: From measured activity concentrations in the air, soil, water, foodstuffs, ambient dose rate (as well as dosimeters, whole-body measurements, and bioassay)
Scenarios and exposure pathways	S2: All realistically and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S2: Case-specific mean values and uncertainties
Consumption habits	S1: Generic mean values and uncertainties
Durations of stay	S3: Generic mean values and uncertainties
Percentage of locally produced foodstuffs	S3: Generic mean values and uncertainties
Uncertainties	GUM Supplement 1

With planned exposure situations, prospective dose estimates represent a special case in licencing nuclear facilities and installations. Here, radiation protection requirements can be made on the basis of the precautionary principle that would be impossible with other applications[12]. This is the approach used in Germany pursuant to the General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV) (Table 3.16) and the Basis of Estimation for Incidents (SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV) (Table 3.17).

[12] Excess demands cannot be made if, as in the case of of NORM industries and contaminated uranium mines, radiation exposure is to be estimated prospectively and such requirements would nullify any capacity to act.

Table 3.16: ***Application II.1-1:*** *Nuclear facilities and installations - licencing - normal operation, General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV).*

Application	**Planned exposure situation, prospective: General Administrative Regulation relating to § 47 of the Radiation Protection Ordinance (StrlSchV)**
Output quantity and values to be calculated	Dose to a reference person at the most unfavourable receiving points; overarching point estimates
Exposure modelling	I0: From a source term
Scenarios and exposure pathways	S0: overarching (also impossible), equilibrium
Radioecological model parameters	S1: Generic mean values
Consumption habits	S0: Generic 95th percentile
Durations of stay	S0: long-term stay
Percentage of locally produced foodstuffs	S0: 100%
Uncertainties	None

Table 3.17: ***Application II.1-2:*** *Nuclear facilities and installations - licencing - incidents and accidents (SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV).*

Application	**Planned exposure situation, prospectively: Basis of Estimation for Incidents (SBG) relating to § 49 of the Radiation Protection Ordinance (StrlSchV)**
Output quantity and values to be calculated	Dose to a reference person at the most unfavourable receiving points; overarching point estimates
Exposure modelling	I0: From a source term
Scenarios and exposure pathways	S0: overarching (also impossible),
Radioecological model parameters	S1: Generic mean values
Consumption habits	S0: Generic 95th percentile
Durations of stay	S0: Duration of stay
Percentage of locally produced foodstuffs	S0: 100%
Uncertainties	None

Application II.1-3 “Monitoring nuclear facilities and installations during normal operation” should be handled in the same way as Applications I.4-1 and I.4-2.

In emergency exposure situations, prospective and retrospective dose estimates must be clearly distinguished from one another. Prospective estimates are very different from retrospective ones due to the differences in information available. Prospective estimates and the resulting decisions for or against implementing emergency protection measures lead to a conflict between the precautionary principle and the principle of proportionality.

This conflict can only be prudently solved for a potential spectrum of FEPs on the basis of dose estimates that are as realistic as possible. Tables 3.18 and 3.22 below contain suggestions for emergency exposure situations.

Only a minimum of information is available during the acute phase of an emerging emergency (Table 3.18). Decisions have to be made quickly in order to avoid deterministic effects and unreasonably high stochastic risks among the general public, particularly in terms of thyroid doses. Due to time pressure, uncertainty estimations will have to be left to expert estimates.

Table 3.18: ***Application II.2-1:*** *SSK emergency response proposal: Stipulation of protective measures - short-term - prospectively based on forecasts.*

Application	**Existing exposure situation, prospective: short-term determination of protective measures**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate
Exposure modelling	I1 → I2: From a source term, forecast or measured
Scenarios and exposure pathways	S1 → S2: Generic or, where available, case-specific and legally feasible; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1: Generic mean values
Consumption habits	S1: Generic mean values, where relevant
Durations of stay	S1: Generic mean values, where relevant
Percentage of locally produced foodstuffs	S1: Generic mean values, where relevant
Uncertainties	None

If environmental radioactivity data and ambient dose rates have been measured and are available, the prospective dose estimates as per Table 3.18 can be superseded by estimates involving Table 3.19 as they are closer to reality.

A particular problem that arises in emergency exposure situations is where the temporal and spatial development of transporting radioactive substances in the environment leads to a smooth transition from the acute phase of an accident to the post-accident phase, and to the coexistence of emergency and existing situations. Prudence is also required here in order to react appropriately and to communicate the actions taken to the general public. Tables 3.19, 3.20 and 3.21 show the various different approaches.

Table 3.19: ***Application II.2-2:*** *SSK emergency response proposal: Stipulation of protective measures - short-term - retrospectively based on activity and ambient dose rate measuring values.*

Application	**Emergency exposure situation, retrospectively: short-term determination of protective measures**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate
Exposure modelling	I3 → I4: Where available during the development of an emergency, from the measured ambient dose rate and activity concentrations in the air, soil, water, foodstuffs and dosimetry
Scenarios and exposure pathways	S1 → S2: Generic or, where available, case-specific and legally feasible; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1: Generic mean values
Consumption habits	S1: Generic mean values
Durations of stay	S1: Generic mean values
Percentage of locally produced foodstuffs	S1: Generic mean values
Uncertainties	None

Table 3.20: ***Application II.2-3:*** *SSK emergency response proposal - remediation.*

Application	**Existing exposure situation, prospectively: Remediation**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty Dose to reference persons among the affected population: best estimate and dose distribution
Exposure modelling	I3 → I4: Where available during the development of an emergency, from the measured ambient dose rate and activity concentrations in the air, soil, water, foodstuffs and dosimetry
Scenarios and exposure pathways	S1 → S2: Case-specific existing and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1 → S2: Generic mean values and uncertainties, case-specific data, where available
Consumption habits	S1: Generic mean values
Durations of stay	S1: Generic mean values
Percentage of locally produced foodstuffs	S1: Generic mean values
Uncertainties	GUM Supplement 1

Table 3.21: ***Application II.2-4:*** *SSK emergency response proposal - Stipulation of protective measures - long-term (suspension of use constraints, resettlement).*

Application	**Existing and emergency exposure situation, prospectively: long-term stipulation of protective measures**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty Dose to reference persons among the affected population: best estimate and dose distribution
Exposure modelling	I3 → I4: Where available during the development of an emergency, from the measured ambient dose rate and activity concentrations in the air, soil, water, foodstuffs and dosimetry
Scenarios and exposure pathways	S1 → S2: Case-specifically existing and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1 → S2: Generic mean values and uncertainties, case-specific data, where available
Consumption habits	S1: Generic mean values
Durations of stay	S1: Generic mean values
Percentage of locally produced foodstuffs	S1: Generic mean values
Uncertainties	GUM Supplement 1

Table 3.22: ***Application II.2-5:*** *SSK emergency response proposal – rescue operations - workers.*

Application	**Emergency exposure situation, prospectively**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty
Exposure modelling	I1 → I3: From a hypothetical or measured source term, and, where available, ambient dose rate and activity concentration data for the soil, air and water
Scenarios and exposure pathways	S2: Case-specific existing (and legally feasible); generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1: Generic mean values
Consumption habits	N/A
Durations of stay	S1: Generic mean values
Percentage of locally produced foodstuffs	Does not apply
Uncertainties	GUM or GUM Supplement 1

Prospective dose estimates are particularly vital to the workers involved in rescue measures and safeguarding the critical infrastructure (Table 3.22). As the dose limits for workers only differ by a few factors from the deterministic damage thresholds, it is essential to analyse uncertainties.

During clearance of radioactive substances, the derivation of general clearance values (table 3.23) has to be distinguished from individual clearances (table 3.24). Naturally, only generic data and hypothetical source terms can be taken as a starting point when deriving clearance values using a 10 μSv per year criterion (IAEA 1988, EC 1993, Deckert et al. 2000, Thierfeldt and Kugeler 2000, SSK 1998). This can be proven by means of past developments in the clearance process for radioactive substances in Germany and other countries (SSK 2005c). Generic FEPs have to be regularly checked for usefulness as factors beyond the scope of radiation protection may change the boundary conditions. This was, for example, the case when a new landfill ordinance questioned the terms of clearance for disposal (see SSK 2007 for more information). In view of the uncertainties of the parameters used to estimate potential radiation exposures, an analysis of uncertainties together with the formerly unpublished GUM Supplement 1 proved to be of use (Thierfeldt et al. 2003).

Table 3.23: ***Application II.3-1:*** *SSK proposal for clearance; derivation of clearance values.*

Application	**Planned exposure situation, prospectively**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty
Exposure modelling	I0: From a hypothetical source term
Scenarios and exposure pathways	S1: Generic, realistically and legally feasible; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1: Generic mean values
Consumption habits	S1: Generic mean values
Durations of stay	S1: Generic values with uncertainties
Percentage of locally produced foodstuffs	S1: Generic mean values
Uncertainties	GUM Supplement 1

In terms of clearance of buildings and land areas, potential dose estimates for individual clearances (Table 3.24) largely fit the character of conventional radioecological dose estimates. In this case, based on a hypothetical source term as a best estimate, it is essential to incorporate case-specific data to the largest possible extent. An analysis of uncertainties is also imperative here.

Table 3.24: ***Applications II.3-2 and II.6-2:*** *SSK proposal for case-specific clearance or release.*

Application	Planned exposure situation, prospectively
Output quantity and values to be calculated	Dose to a representative reference person from the general public at a single location: best estimate with uncertainty Dose to reference persons among the affected population: best estimate and dose distribution Employee dose: best estimate with uncertainties
Exposure modelling	I1 → I2*: From a hypothetical source term
Scenarios and exposure pathways	S1 → S2: Generic, realistically and legally feasible; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1 → S2: Generic mean values or case-specific data with uncertainties
Consumption habits	S1 → S2: Generic mean values or case-specific data with uncertainties
Durations of stay	S1 → S2: Generic values or case-specific data with uncertainties
Percentage of locally produced foodstuffs	S1 → S2: Generic mean values or case-specific data with uncertainties
Uncertainties	GUM Supplement 1

* In individual cases where areas are authorised up to I4

Similarly to dose estimates for clearances, when releasing residues requiring surveillance, estimates should be dealt with as set out in §§ 95, 96, 97, 98, 101 and 102 of the Radiation Protection Ordinance (StrlSchV). As with the clearance of wastes, existing, potential and future radiation exposures for the general public and workers should also be considered during the release of residues from surveillance. These estimates serve as proof of compliance with the 1 mSv per year constraint. Tables 3.32 and 3.33 both contain SSK proposals to this end.

The prediction of potential radiation exposure for the final storage of radioactive waste forms the basis of every long-term safety analysis. This involves extreme cases of prospective estimates of potential radiation exposure as a potential radionuclide contamination from a final nuclear waste repository at a nearby biosphere close to the surface may only occur in the distant future, i.e. in tens or hundreds of thousands of years (the possibility of human intrusion at the final nuclear waste repository is disregarded). For such periods of time, it is not possible to provide forecasts regarding cultural development, human behaviour or forms of use. In addition, there are major uncertainties in terms of developments at the final nuclear waste repository, climatic change, prevailing hydrological conditions and, despite being of less importance than the aforementioned factors, the development of geological conditions. When it comes to long-term safety, dose estimates are merely indicator values representing a relative measure of final nuclear waste repository safety, but cannot be used to estimate actual future radiation exposure.

Another characteristic of dose estimates in the decommissioning of a final nuclear waste repository is the fact that potential radionuclide contamination of a nearby biosphere close to the surface may also take a very long time (tens or hundreds of thousands of years), meaning that a wide range of exposure scenarios may develop. Even if it were possible to provide a realistic dose estimate for the distant future, it would have to incorporate a number of successive scenarios, meaning that there would not just have to be one realistic estimate, but one for each different period of time.

These are all reasons why it is not possible to provide a realistic dose estimate for the long-term safety assessment. Instead, an indicator representing the dose is calculated for a representative reference person or several representative reference persons whose behaviour is stipulated as a convention. The conditions of the Earth's surface, i.e. the postulated biosphere near to the surface, also need to be stipulated as a convention. An estimate of radionuclide concentrations in the groundwater forms part of this calculation. As this is a consequence of known natural processes covered by the principle, the need for as much realism as possible can be applied to this part of the dose calculation. Here, extremely conservative overestimates can lead to the feasibility of final storage being generally called into question. In the future, restrictive underestimates can prevent protection goals from being met for future generations. Again, only best estimates can lead to a balanced assessment of safety at a final nuclear waste repository. However, existing uncertainties also need to be fully ascertained and considered.

In the event of significant uncertainties in terms of the presence of system properties or the occurrence of processes that influence system development, estimations of radionuclide concentrations in groundwater have to be made along with dose calculations for various scenarios representing potential developments that are based on the groundwater radionuclide concentration estimates.

If there are any uncertainties when it comes to the scope of the system properties and processes, they can be described using parameter uncertainties. Parameters that indicate variability within the system and for which the information or data available allow for the derivation of a reasonable PDF, can be dealt with in the same way as the cases above, i.e. within the scope of conventional uncertainty analyses pursuant to GUM Supplement 1.

In cases where these requirements are not met, it may be necessary to use other methods that account for existing uncertainties such as the definition of bandwidths, the multi-dimensional Monte Carlo simulations, and p-Box methodologies (Barthel and Thierfeldt, 2012).

Tables 3.25 and 3.26 show the current state of discussion within the SSK in terms of the approach for long-term safety analyses for final nuclear waste repositories divided into forecasts for foreseeable periods of time and long-term estimates. The content of these tables should be used for information purposes and not understood as being the result of the pending consultation on “Radioecological models and calculation guidelines for final storage”.

Table 3.25: ***Application II.4-2:*** *SSK proposal for long-term safety analysis at final nuclear waste repositories – state of discussion for forecasts over foreseeable periods of time.*

Application	**Planned exposure situation, prospectively: safety case**
Output quantity and values to be calculated	Dose to a representative reference person at the most unfavourable receiving point (most exposed individual): best estimate with uncertainty
Exposure modelling	I1: From a hypothetical source term
Scenarios and exposure pathways	S1: All realistically feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S2: Case-specific mean values and uncertainties
Consumption habits	S1: Generic mean values and uncertainties
Durations of stay	S1: Generic mean values and uncertainties
Percentage of locally produced foodstuffs	S1: Generic mean values and uncertainties
Uncertainties	GUM Supplement 1 + multidimensional MC

Table 3.26: ***Application II.4-3:*** *SSK proposal for long-term safety analysis at final nuclear waste repositories – state of discussion for long-term estimates.*

Application	**Planned exposure situation, prospective: safety case**
Output quantity and values to be calculated	Dose to a representative reference person at the most unfavourable receiving point, indicator value with uncertainty
Exposure modelling	I1: From a hypothetical source term
Scenarios and exposure pathways	S1: All realistically feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases Incorporation of the various different climatic developments and biosphere conditions
Radioecological model parameters	S1: Case-specific mean values and uncertainties (GUM Supplement 1 + multidimensional MC)
Consumption habits	S1: Generic values
Durations of stay	S1: Generic values
Percentage of locally produced foodstuffs	S1: Generic values
Uncertainties	GUM Supplement 1 + multidimensional MC

Estimates of actual or potential doses to the general public play a pivotal part in assessing radiologically contaminated sites as situations with permanent radiation exposure. Also of importance here are estimates of actual or potential doses to workers and members of the general public resulting from remediation measures which, in terms of exposure estimation, are to be handled in the same way as planned exposure situations.

The application of the Calculation Guide Mining (BglBb) was originally limited to assessing and remediating contaminated uranium mines in Saxony and Thuringia, but this can now be applied to a much larger scope. The Calculation Guide Mining (BglBb) (BMU 1999a, 1999b, BfS 2010) was created as a set of rules on how to retrospectively and prospectively deal with current exposure situations. Further information about this is available in annex A-1.3.

Tables 3.27 to 3.30 show the SSK estimates regarding the current state of radiation exposure estimates as set out in the Calculation Guide Mining (BglBb). However, the recommendations in the tables go beyond the current state as they call for the inclusion of estimated dose uncertainty analyses.

A problem not covered by the Calculation Guide Mining (BglBb) is that of the long-term effects of remediated contaminated sites. In order to treat radiation exposure from natural and artificial radiation sources equally, this question should form part of the general discussion regarding long-term safety.

Table 3.27: ***Application II.5-1:*** *Contaminated sites – workers (Calculation Guide Mining (BglBb) level 1).*

Application	**Retrospectively or prospectively**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty
Exposure modelling	I3: From the ambient dose rate and activity concentrations in the air, soil, water and foodstuffs
Scenarios and exposure pathways	S1: All realistically and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1: Generic mean values and uncertainties
Consumption habits	N/A
Durations of stay	S1: Generic mean values and uncertainties
Percentage of locally produced foodstuffs	N/A
Uncertainties	GUM or GUM Supplement 1

Table 3.28: ***Application II.5-1:*** *Contaminated sites – workers (Calculation Guide Mining (BglBb) level 2).*

Application	**Retrospective or prospective**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty
Exposure modelling	I3 → I4: From measured activity concentrations in the air, soil, water, foodstuffs, if available ambient dose rate (as well as dosimeters, whole-body measurements, and bioassay)
Scenarios and exposure pathways	S2: All case-specific and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S2: Case-specific mean values and uncertainties
Consumption habits	N/A
Durations of stay	S2: Case-specific data and uncertainties
Percentage of locally produced foodstuffs	N/A
Uncertainties	GUM or GUM Supplement 1

Table 3.29: ***Application II.5-2:*** *Contaminated sites – general members of the public (Calculation Guide Mining (BglBb) level 1).*

Application	**Existing exposure situation, retrospectively or prospectively**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty or PDF
Exposure modelling	I3: From the measured ambient dose rate and activity concentrations in foodstuffs modelled from data measured for the air, soil and water
Scenarios and exposure pathways	S1: All realistically and legally feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1: Generic mean values and uncertainties
Consumption habits	S1: Generic mean values and uncertainties
Durations of stay	S1: Generic mean values and uncertainties
Percentage of locally produced foodstuffs	S1: Generic mean values and uncertainties
Uncertainties	GUM or GUM Supplement 1

Table 3.30: ***Application II.5-2:*** *Contaminated sites – general members of the public (Calculation Guide Mining (BglBb) level 2).*

Application	**Planned exposure situation, retrospectively or prospectively**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty
Exposure modelling	I4: From measured activity concentrations in the air, soil, water, foodstuffs, ambient dose rate (as well as dosimeters, whole-body measurements, and bioassay)
Scenarios and exposure pathways	S1 – S2: All or generic or case-specific realistically and legally feasible; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S2: Case-specific mean values and uncertainties
Consumption habits	S1 → S2: Generic mean values or case-specific data with uncertainties
Durations of stay	S1 → S2: Generic mean values or case-specific data with uncertainties
Percentage of locally produced foodstuffs	S1 → S2: Generic mean values or case-specific data with uncertainties
Uncertainties	GUM or GUM Supplement 1

Radiological protection does not cover the derivation of trigger or action values customary in conventional environmental protection to assess existing exposure situations. To this end, Table 3.31 contains a proposal that could be implemented in a future Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV).

Table 3.31: ***Application II.5-3:*** *SSK proposal for contaminated sites – derivation of trigger or action values.*

Application	**Existing exposure situation, retrospectively or prospectively**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty
Exposure modelling	I0: From a hypothetical source
Scenarios and exposure pathways	S1: All realistically (and legally) feasible; generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S1 → S2: Generic or case-specific mean values and uncertainties
Consumption habits	S1: Generic mean values and uncertainties
Durations of stay	S1: Generic mean values and uncertainties
Percentage of locally produced foodstuffs	S1: Generic mean values and uncertainties
Uncertainties	GUM or GUM Supplement 1

Applications II.5-4, II.5-5 and II.5-6 are to be dealt with in the same way as II.5-1 or II.5-2.

In order to protect the general public against naturally occurring radioactive substances in residues and other materials, the Radiation Protection Ordinance (StrlSchV) includes surveillance limits for the specific activity. If this is exceeded, it can be assumed that the effective dose of 1 mSv per year for individual members of the public may be exceeded. A dose estimate is only required in the event of a release of residues pursuant to § 98 of the Radiation Protection Ordinance (StrlSchV), when checking properties to make sure they are free of contamination (§ 101 of the Radiation Protection Ordinance (StrlSchV)), and, where required, to assess materials to determine whether surveillance is needed pursuant to § 102 of the Radiation Protection Ordinance (StrlSchV) (see Tables 3.32 and 3.33).

Table 3.32: ***Application II.6-1:*** *SSK proposal for dose estimates in NORM industries - workers.*

Application	**Planned or existing exposure situation, retrospectively and prospectively**
Output quantity and values to be calculated	Dose to a representative reference person at a single location: best estimate with uncertainty
Exposure modelling	I1 (prospectively) – Hypothetical source term for planning practices as intended by the new Euratom Basic Safety Standards I2: Actual source term of facilities and/or processes that have already been in operation
Scenarios and exposure pathways	S2: Case-specifically existing (and legally feasible); generic; disequilibria; incorporation of all processes relevant to radionuclide releases
Radioecological model parameters	S2: Case-specific values with uncertainties provided they can be practically determined
Consumption habits	N/A
Durations of stay	S2: Case-specific data and uncertainties
Percentage of locally produced foodstuffs	N/A
Uncertainties	GUM or GUM Supplement 1

Table 3.33: ***Application II.6-2:*** *SSK proposal for dose estimates due to naturally occurring radioactive material in residues and other material - general public.*

Application	**Planned exposure situation, prospectively**
Output quantity and values to be calculated	Dose to a representative reference person from the general public at a single location: best estimate with uncertainty
Exposure modelling	I1 → I2: With any material that may arise in future from hypothetical source term I1; with existing material from real source term I2
Scenarios and exposure pathways	S1 → S2: Members of the general public: taking into consideration the respective location, generic, realistic and legally feasible
Radioecological model parameters	S1 → S2: For disposal processes at specific facilities: case-specific values where available (S2), otherwise generic values (S1)
Consumption habits	S1: Generic mean values with uncertainties
Durations of stay	S1 → S2: Members of the general public: taking into consideration the respective location, generic, realistic and legally feasible
Percentage of locally produced foodstuffs	S1 → S2: Generic mean values or case-specific mean values with uncertainties
Uncertainties	GUM Supplement 1

3.5.3 Recommendation summary

This SSK recommendation for dose estimation serves as a proposal for drafting the realism requirement set out in article 45 of the Euratom Basic Safety Standards. Table 3.34 summarises the recommendations that have been described in detail in this proposal.

Table 3.34: SSK proposal for the various application scopes of dose estimates with recommendations from information categories Ii and situation categories Sj including the uncertainties u(D) or PDF.

	Application scopes	**ICRP [a)]**	**Ii; Sj; u(D) or PDF**	**Purpose**
I	**Information**			
I.1	**Natural radiation exposure**	EX	I3 → I4; S1; PDF	Parliamentary report
I.2	**Nuclear weapons testing**	EX	I3 → I4; S1; u(D)	Parliamentary report
I.3	**Chernobyl**	EX	I3 → I4; S1; PDF	Parliamentary report
I.4	**Nuclear technology, technology, research, medicine (for reporting purposes)**			

	Application scopes	ICRP [a)]	Ii; Sj; u(D) or PDF	Purpose
I.4-1	Radiation exposure among reference groups or members of the general public resulting from practices during normal operation	P	I2; S1 → S2; u(D) or PDF	EU Art. 45 parliamentary report
I.4-2	Radiation exposure among reference groups or members of the general public resulting from practices after incidents and accidents	EX	I2 → I4; S1 → S2 ; PDF	EU Art. 45 parliamentary report
I.5	**Epidemiological research**			
I.5-1	Epidemiological research; cohort and case-control studies	EX, EM	I4; S3; PDF	Science
I.5-2	Epidemiological research; ecological studies	EX	I4; S1 → S2, PDF	Science
II	**Limitation of doses by limit, constraint, reference and indicator values: Planning and monitoring**			
II.1	**Construction and operation of nuclear plants and facilities subject to authorisation as stipulated in § 47 of the Radiation Protection Ordinance (StrlSchV)**			
II.1-1	Licence - normal operation	P	I0; S0 (S1 for radioecological model parameters), none	§§ 13, 46 and 47 of the Radiation Protection Ordinance (StrlSchV)
II.1-2	Licence – incidents and accidents	P	I0; S0 (S1 for radioecological model parameters), none	§ 49 of the Radiation Protection Ordinance (StrlSchV)
II.1-3	Monitoring - normal operation	EX	I2; S1 → S2; none	Licencing conditions
II.2	**Emergency management**			General: §§ 51 to 58 of the Radiation Protection Ordinance (StrlSchV)
II.2-1	Stipulation of protective measures - short-term - prospectively (based on forecasts)	EM	I1 → I2; S1 → S2 ; none	
II.2-2	Stipulation of protective measures - short-term - retrospectively (based on activity measuring values)	EM	I3 → I4; S1 → S2; none	
II.2-3	Remediation	EX	I3 → I4; S1 → S2; PDF	
II.2-4	Stipulation of protective measures - long-term (elimination of use constraints, resettlement)	EM, EX	I3 → I4; S1 → S2; PDF	
II.2-5	Rescue operations - workers	EM	I1 → I3; S1 (→ S2); u(D) or PDF	§ 59 of the Radiation Protection Ordinance (StrlSchV)
II.3	**Clearance**			
II.3-1	Derivation of clearance values	P	I0; S1; PDF	§ 29 of the Radiation Protection Ordinance (StrlSchV)

	Application scopes	ICRP [a)]	Ii; Sj; u(D) or PDF	Purpose
II.3-2	Clearance on a case-specific basis	P	I1 → I2[b)]; S1 – S2; PDF	§ 29 of the Radiation Protection Ordinance (StrlSchV)
II.4	**Long-term safety analysis at final nuclear waste repositories**			
II.4-2	State of discussion for forecasts over foreseeable periods of time	P	I1; S1 → S2; PDF	ESK/SSK + ICRP
II.4-3	State of discussion for long-term assessments[c)]	P	I1; S1; PDF	
II.5	**Contaminated sites**			
II.5-1	Workers		I3 – I4; S1 → S2; u(D) or PDF	§ 95 et seq. of the Radiation Protection Ordinance (StrlSchV)
II.5-2	Members of the general public	P, EX	I3 – I4; S1 → S2; u(D) or PDF	Calculation Guide Mining (BglBb)
II.5-3	Derivation of trigger or action values	EX	I0; S1 (S1 → S2 for radioecological model parameters); u(D) or PDF	*(does not exist yet)*
II.5-4	Individual case / current situation	EX	I2 → I4; S1 → S2; u(D)	
II.5-5	Individual case / during remediation	EX	I3 → I4; S1 → S2; PDF	
II.5-6	Individual case / future (with/without remediation)	EX	I1 → I3; S1; PDF	
II.6	**Standard**			
II.6-1	Workers	EX, P	I1 (hypothetical source term), I2 (actual source term); S2; u(D) or PDF	§§ 95 and 96 of the Radiation Protection Ordinance (StrlSchV)
II.6-2	Members of the general public	P	I1 → I2; S1 → S2; PDF	§§ 97, 98, 101, 102 of the Radiation Protection Ordinance (StrlSchV)

a) This column characterises exposure situations based on ICRP 103:
P: planned exposure situations, EX: existing exposure situations, EM: Emergency exposure situations.

b) In individual cases where areas are authorised up to I4

c) The potential dose estimates for long-term final nuclear waste repository and contaminated site assessments only constitute indicator values within the scope of long-term safety assessment considerations.

“u(D)”: Uncertainties based on GUM (JCGM 2008a)

PDF: Uncertainties based on GUM Supplement 1 (JCGM 2008b)

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H.-H. Landfermann:	Rechtliche Anforderungen und Überlegungen an die Realität der Ermittlung der Strahlenexposition
G. Kirchner:	Realistische Ermittlung der natürlichen Strahlenexposition in Deutschland
L. Hornung-Lauxmann:	Empfehlungen der EU zur realistischen Ermittlung der Strahlenexposition: RP 129
G. Pröhl:	Konservativitäten bei der Berechnung der Strahlenexposition durch Ingestion nach AVV
U. Janicke:	Realistische Ausbreitungsrechnungen: AUSTAL 2000
R. Metzke:	Aufsichtsverfahren
S. Thierfeldt:	Konservativitäten bei der Berechnung neue Modellentwicklung bzgl. der Freigabe in Deutschland
J. Titley:	Dose from effluents due to the reprocessing plant Sellafield
R. Michel:	Realistic dose and risk assessment for Cap de la Hague
P. Jacob:	Dosisverteilungen und kritische Bevölkerungsgruppen nach Tschernobyl.
R. Michel:	Ermittlung der Strahlenexposition von Rückwanderern in die evakuierten Gebiete der nördlichen Ukraine
H. Müller, G. Pröhl:	Realistische Dosisabschätzung nach unfallbedingten Radionuklidfreisetzungen
R. Konietzka:	Expositionsszenarien der Bundes-Bodenschutz- und Altlastenverordnung -Wirkungspfad Boden – Mensch
R. Barthel, P. Schmidt:	Realistische Abschätzung von Strahlenexpositionen durch Hinterlassenschaften des Uranbergbaus
H. Schul, /L. Funke:	Strahlenexposition bei der Demercurisierung, Immobilisierung und Deponierung von Rückständen der Erdöl-Erdgasgewinnung
S. Kistinger:	Unsichere Größen bei der Abschätzung von Strahlenexpositionen durch Altablagerungen: Grundwasserpfad
E. Schnug:	Transferfaktoren Boden–Pflanze: Methoden der Bestimmung und Einflussfaktoren