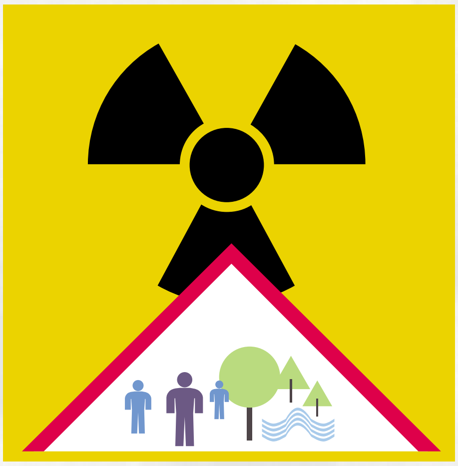
European Commission

Radiation protection 122

Practical use of the concepts of clearance and exemption

Part II
Application of the concepts of exemption and clearance to natural radiation sources



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European Commission

Radiation protection 122

Practical Use of the Concepts of Clearance and Exemption – Part II

Application of the Concepts of Exemption and Clearance
to Natural Radiation Sources

Directorate-General
Environment

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Foreword

Part I of this publication gives guidance on the application of the concepts of exemption and clearance to practices. Further to earlier guidance on specific clearance levels (in activity per unit mass) for the recycling of metals and building rubble from dismantling of nuclear installations, part I has introduced the concept of general clearance levels: default values, for materials arising from any practice, any type of material and any pathway of recycling or reuse.

This concept has been developed in this part II for materials arising from industries which mine or process ores or other materials for which the presence of naturally occurring radionuclides are of concern. Such NORM materials are dealt with in Title VII of the Basic Safety Standards (work activities for which enhanced exposure to natural radiation sources is of concern). While the Directive introduced for the first time detailed requirements for the regulatory control of such work activities, it left at the same time a lot of flexibility to Member States for proceeding with the identification of work activities that are of concern and for defining the extent of regulatory control, applying all or part of the requirements for practices as appropriate for each type of work activity.

Since the adoption of the Directive and while preparing for the implementation of its provisions in national legislation, Member States have considered that there was merit in using the concept of reporting and prior authorisation and its corollaries, exemption and clearance, laid down in Title III of the Directive for practices, to work activities as well.

This publication, adopted by the Group of Experts established under Article 31 of the Euratom Treaty, gives guidance on how Member States could use these concepts and on which general clearance levels would be appropriate.

The main conclusions of this work are the following:

- As a result of the large volumes of material processed and released by NORM industries, the concept of exemption and clearance merge, and it is appropriate to lay down a single set of levels both for exemption and clearance;

- While the basic concept and criteria for exemption-clearance for work activities are very similar to those for practices, it is not meaningful to define the levels on the basis of the individual dose criterion for practices (10 µSv per year); instead a dose increment, in addition to background exposure from natural radiation sources, of the order of 300 µSv is appropriate.

On this basis exemption-clearance levels for NORM materials have been calculated, rounded to 0.5 $Bq.g^{-1}$ for Uranium and Thorium in secular equilibrium. This is in the upper range of concentrations usually found in ores and thus ensures that regulatory control is practicable. The merit of deriving values from a dose criterion is that it offers a coherent and transparent approach, and allows higher clearance levels to be derived for segments of the decay chain of the parent radionuclides.

In the same way as in part I, this publication offers all information on the scenarios and parameter values that were used for the calculation of the concentration levels. In addition to offering full transparency, this will allow Member States and industries to examine whether the generic assumptions are valid for a specific work activity.

While this publication introduces a single set of concentration levels both for exemption and for clearance, the Commission wishes to emphasise that the concept of exemption requires a fixed set of levels allowing industries to decide whether they should report to the authorities or not. The concept of clearance, in the same way as for practices, must be applied by the authorities with some flexibility, allowing for specific features of industries and for the best option for the management of residual materials. In the context of clearance, the proposed levels have the same status as the reference levels for the identification of industries on the basis of workers' exposure. There is little benefit in having a rigid threshold above which materials would be regarded as radioactive waste. In the context of exemption, it should be noted that the concentration values have been derived on the basis of scenarios involving very large volumes of materials. While no values have been proposed for exempted quantities, it is clear that regulatory authorities may wish to exempt moderate amounts of material at activity levels above the exempt concentration (e.g. potassium salts, geological samples, …).

Finally, it should be explained how the guidance in part I and part II should be understood in relation to natural radionuclides which are regulated as a practice in view of the fact that they have been processed to use their fissile of fertile properties in the nuclear fuel cycle. While the general clearance levels in part I may in principle apply to the release of materials from regulated practices (e.g. uranium mining, milling and processing), it may in practice often not be possible to verify compliance as a result of the high natural background. As for the application of the exemption values, it is clear that an industry receiving materials cannot distinguish between materials which are residues from a practice or from a work activity. Hence the recipient will logically use the general levels for work activities as proposed in this part II. It is recalled that for natural radionuclides in part I, reference is made to the forthcoming guidance in part II.

The Commission welcomes the guidance provided by the Group of Experts and is confident that it will prove to be very useful to Member States for the implementation of the requirements of the Basic Safety Standards with regard to natural radiation sources. It should be emphasised however that there is no obligation for Member States to adopt these recommendations. In addition, it should be looked at in conjunction with earlier guidance on the application of Title VII of the Directive.

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1. INTRODUCTION

The concepts of *exemption* of practices and *clearance* of materials have been introduced in the new Basic Safety Standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation (Council Directive 96/29/EURATOM, adopted on 13 May 1996)[1]. In this way the Basic Safety Standards provide a complete framework for the administrative requirements enabling an appropriate regulatory control of practices, commensurate to their radiological impact. These concepts relate to different ways of avoiding wastage of regulatory resources in cases where there would be no or nothing but a trivial benefit.

The concepts of exemption and clearance relate to the regulatory control of *practices* as discussed in Part I. In addition to the two categories of situations identified by ICRP (publication 60: *intervention* and *practices*), the Directive introduces a third category: *work activities* involving exposure to natural radiation sources. In the ICRP recommendations such exposures are regarded either as an intervention situation (e.g. radon in dwellings) or as practices. The Directive considers this new area of radiation protection in its own right. It is dealt with in a separate Title VII of the Directive which allows a flexible approach based at the same time on the principles of intervention and of practices.

Within the context of natural radiation sources the concept of *exclusion* is also introduced: certain categories of exposure to natural radiation sources are not amenable to control: they have been excluded from the scope of the Directive and need not be accounted for in the total exposure. For the sake of clarity the Directive restricts the concept of exclusion to exposures which are not amenable to control. Thus all work activities that can in principle be controlled are in the scope of the Directive, but the national authorities may conclude that controls are not sufficiently justified by the possible reduction of exposure. Such a decision is however part of the regulatory framework and hence it is not appropriate to stretch the concept of exclusion to encompass categories of work activities. Within a scheme for regulatory control of work activities decided upon by national authorities there is nevertheless room for excluding (or not including) part of the exposure to natural radiation sources from the total exposure.

The application of the concepts of exemption and clearance to natural radiation sources is discussed in this Part II within the overall context of regulatory control of natural radiation sources and in particular as laid down in Title VII of the Basic Safety Standards for work activities. The concepts of exemption and clearance are relevant to industries processing ores or other NORM (naturally occurring radioactive materials), and they are discussed together with other approaches to optimise the use of regulatory resources. Finally, enveloping scenarios are proposed for establishing exemption and clearance values for naturally occurring radionuclides.

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1 Council Directive 96/29/EURATOM, OJ L 159, 29.06.96, p. 1-114.
http://europa.eu.int/comm/environment/radprot/index.htm

2. REGULATORY CONTROL OF NATURAL RADIATION SOURCES

2.1. Work activities

Within the scope of the Directive (Article 2) with regard to natural radiation sources a distinction is made between:

1. Utilisation of natural radionuclides *which are or have been processed in view of their radioactive, fissile or fertile properties*. Such cases are considered practices and all the provisions of the Directive on practices apply.

A distinction on the basis of the intended use of a radionuclide may in fact not always be practicable, in particular when the practice is terminated. Upon receipt of metal for recycling, for instance, it will often not be possible to determine whether the origin of the material is a work activity rather than e.g. uranium mining. Uranium mining is a practice, and in the past criteria has been defined to establish whether an ore is uranium-grade.

2. Work activities where the presence of natural radiation sources leads to *a significant increase* in the exposure of workers or members of the public (and the material is not used because of its radioactive, fissile and fertile properties). The Directive applies to these work activities in accordance with Title VII.

Excluded exposures should not be taken into account in the exposure resulting from work activities.

The Directive does not apply to exposure to radon in dwellings or to natural levels of radiation which have been deemed to be excluded, i.e. to naturally occurring radionuclides contained in the human body (e.g. K-40), to cosmic radiation prevailing at ground level or to above ground exposure to radionuclides present in the earth's crust.

2.2. Building materials

In the same way as radon in dwellings is excluded it is understood that external exposure from traditional building materials (stones, bricks, …) is in general excluded. However, residues from work activities such as fly-ash from coal-fired power stations, by-product gypsum and certain slags which are produced in large volumes may be recycled in or used as building materials, and one could argue that such recycling or reuse is cause of an enhanced exposure pathway. Nevertheless, it is important to have a coherent policy with regard to natural and by-product materials. Specific guidance[2] has been given by the Group of Experts established under Article 31 – Euratom Treaty. An activity index is proposed corresponding to the excess gamma exposure (compared to that received outdoors); below an exposure increment of 300 μSv per year it is recommended that building materials would be exempted from any restrictions.

2 Radiation Protection 112, *Radiological protection principles concerning the natural radioactivity of building materials*, 2000, ISBN 92-828-8376-0 http://europa.eu.int/comm/environment/radprot/122/rp-122-en.pdf

2.3. Intervention situations

While clean-up of the contaminated site of an ongoing practice and decommissioning are subject to the requirements for practices, old sites, in particular with residues of NORM industries not previously regulated, would normally be dealt with as intervention situations. Hence also materials arising from clean-up of past or old work activities could be dealt with on the basis of the principles for intervention, even though they may give rise to an increase of the exposure of members of the public elsewhere.

Inversely, while industries processing large amounts of NORM are brought within the scope of the Directive, it is important to account for the fact that possible restrictions on the discharge of effluents for such industries have implications on the amount of residues stored on-site. This must be allowed for in the context of optimisation of protection.

A coherent approach between the control of ongoing work activities and the restoration of old sites must be developed.

2.4. Radon in dwellings

While radon in dwellings is excluded from the Basic Safety Standards Directive, there is a Commission Recommendation on the protection of the public against indoor exposure to radon (90/143/EURATOM)[3]. It was recommended that where a reference level of 400 Bq m^{-3} is exceeded, simple but effective remedial action should be considered. For constructions after 1990 a design level of 200 Bq m^{-3} was recommended.

In the guidance on building materials, it is proposed that radon exhalation can be ignored if it does not cause this design level to be exceeded (which is the case if gamma exposure is controlled on the basis of the index).

A similar approach would be reasonable for indoor exposure resulting from any residues from work activities.

2.5. Drinking water

Council Directive 98/83/EC[4], on the quality of water intended for human consumption, includes radioactivity in the list of indicator parameters (Part C to Annex 1). The parameter is expressed in terms of “total indicative dose” (parametric value 0.1 mSv) including exposure to naturally occurring radioactive substances (except K-40, radon and radon decay products). The indicative dose will be translated into monitoring frequencies, methods and locations in a modified Annex II (not yet published) to this Directive. Guidance to this effect has been given by the Article 31 Experts (November 1999) on the basis of monitoring for α-β activity or for reference nuclides such as Uranium or Ra-226.

The requirements of the Directive need to be taken into account in addition to the specific assessment of pathways of exposure to members of the public from work activities by ingestion, e.g. by infiltration in the water table. On the one hand compliance with the parameter values in the Directive may represent an additional constraint, on the other hand the Directive requires extensive monitoring of public water supplies and hence ensures

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3 OJ L 80, 27.03.90, p. 26-28.

4 OJ L 330, 05.12.98, p. 32-54.

additional protection. It should be noted however that the Directive does not apply to private wells, and hence exposure pathways via such wells may need to be taken into account, unless excluded on the basis of other (national) legislation.

Radon and decay products being excluded from the Directive, the Article 31 Experts have proposed a Commission Recommendation (not yet published) on radon in domestic water supplies, similar to the one on radon in dwellings.

3. TITLE VII (SIGNIFICANT INCREASE IN EXPOSURE DUE TO NATURAL RADIATION SOURCES)

3.1. Introduction

The provisions on work activities involving exposures to natural radiation sources are given in Title VII of the Basic Safety Standards Directive. Articles 40 and 41 establish a stepwise system in which the Member States are required 1) to identify, by means of surveys or by any other appropriate means, work activities which may be of concern 2) to set up appropriate means for monitoring exposure in the identified work activities and as necessary 3) to implement corrective measures to reduce exposure pursuant to Title IX (Intervention, i.e. the optimisation of the form, scale, duration of the intervention), and 4) to apply all or part of the system of radiological protection for practices or interventions, as prescribed elsewhere in the Directive.

The structure of the Directive is such that a priori all work activities are within the scope of the Directive. It is up to Member States to identify which work activities are of concern and require an appropriate form of regulatory control. In the case of radon exposure nation-wide radon surveys in dwellings and workplaces in addition to geological information are means of identification. Surveys will also relate to the characteristics of industries processing materials with (enhanced levels of) naturally occurring radionuclides (NORM).

The approach of Title VII is thus rather general offering flexibility for the Member States to take into account national circumstances. Such flexibility is necessary in view of the fact that in most Member States there is little experience with the regulation of natural radiation sources and in addition a new legal framework must be set up for this purpose. It would nevertheless be advantageous if Member States in the EU would adopt similar approaches in identifying the relevant work activities, in taking corrective measures and in applying the system of radiological protection in occupational and in public exposure.

The economic implications of controls imposed on industries processing raw materials may be such as to require a harmonised policy. The Group of Experts referred to in Article 31 of the Euratom Treaty has recognised this need and has provided technical guidance[5] on the implementation of a system of protection (not only for NORM but also for radon in workplaces and for exposure of aircrew to cosmic radiation).

5 Radiation Protection 88. *Recommendations for the implementation of Title VII of the European Basic Safety Standards Directive (BSS) concerning significant increase in exposure due to natural radiation sources*, 1997, ISBN 92-827-5336-0
http://europa.eu.int/comm/environment/radprot/index.htm#publications

3.2. Implementation of a system of protection

Article 41(b) of Title VII of the Basic Safety Standards states that it shall be required, as necessary, to apply all or part of the system of radiation protection for practices (Titles III, IV, V, Title VI for workers, and Title VIII for members of the public). "All or part" means that the extent of regulatory control can be defined as appropriate, commensurate to the nature of the work activity and taking into account the monitoring results. In the guidance of the Article 31 Experts, boundaries are proposed expressed in terms of radon concentration (Action Level) in places of work and in terms of annual effective dose to workers.

Action Level for Radon in workplaces

It is recommended that the Action Level for places of work should be set in the range 500-1000 Bq m^{-3} time averaged radon gas concentration, equivalent to an effective dose range of 3 to 6 mSv. Occupational exposures to radon above the Action Level will be subject to regulatory control. However, it is expected that the normal response to finding that radon levels in a workplace are above the Action Level will be to undertake remedial measures so that the regulations need no longer be applied.

The term "Action Level" has received the connotation of an intervention level in case of prolonged intervention situations (IAEA, ICRP). In the EU guidance, it is at the same time a reference level for the identification of places of work and for remedial action. In addition, the part of the exposure to radon below the action level is de facto excluded from the overall exposure, in the same way as "background radiation" is excluded from external exposure.

Control of Exposure of Workers

The important routes of exposure of workers from the processes involving naturally occurring radionuclides are normally external gamma radiation and inhalation of dust. The appropriate control measures may include special arrangements for the storage of bulk materials, limitation of exposure time and dust control. In some cases radon or thoron may present a problem and surface contamination may also need to be considered.

Normal common-sense precautions should be taken to avoid all unnecessary exposures to radiation. Beyond this, assessments should be made to estimate the doses to workers from such natural radionuclides. If actual doses are less than 1 mSv per year then no special precautions are required. If annual doses exceed 1 mSv then the normal scheme for controlling exposures can usually be applied. If doses exceed 6 mSv then it may be appropriate to define a controlled area.

If actual doses exceed 1 mSv but are less than 6 mSv it would be appropriate to consider, for example, whether doses could effectively be reduced and whether there is a possibility that doses increase either over time or as the result of an accident. If doses are low and cannot effectively be reduced and if there is no realistic potential for accidents then few radiation protection measures are likely to be required beyond whatever is necessary to ensure that doses do not increase.

Guidance on the exposure of aircrew is broadly consistent with the annual effective doses referred to above for terrestrial natural radiation sources.

Control of Exposure of the Public

Exposures of the public may arise from the product of a process, from atmospheric or liquid discharges, from re-use of by-product material or from disposal of solid waste. The important routes of radiation exposure of the public are external gamma radiation, inhalation and ingestion.

The requirements for members of the public are laid down in Title VIII of the Basic Safety Standards. Article 47 stipulates that the undertaking responsible for a practice shall be responsible for achieving and maintaining an optimal level of protection for the environment and the population.

There is currently no guidance as to which dose constraints should apply to the exposure of members of the public as a result of work activities.

It should be noted that the distinction between workers and members of the public is not always clear. The exposure of a worker processing materials containing residues from other industries may in some cases be regarded in the same way as the inadvertent exposure of a member of the public.

4. INDUSTRIES PROCESSING NORM

4.1. Introduction

It should be noted that the degree of exposure depends not only on the activity concentration of the material involved but also on any chemical or physical processing which may increase the availability of the material. For example, grinding up raw materials may generate respirable dusts and may also make it easier for radon to escape into the air of the workplace. Processing materials rich in uranium or thorium families at high temperatures (e.g. coal combustion, about 800° C) could enrich airborne dust in some radionuclides of the uranium and thorium series, e.g. Po-210 and Pb-210. At very high temperatures (about 3000° C or above) other nuclides of the uranium or thorium families may also gasify, e.g. Ac-228 may gasify from welding rods doped with Th-232 during welding. Dust and volatile radionuclides may be discharged through the stack or they may accumulate on filters and need to be disposed of.

Solid residues of some industries may also contain enhanced levels of radionuclides. Disposal or reuse of such materials may be significant especially with regard to public exposure. Scales deposited on steel pipes (oil and gas industry) are a possible source of exposure upon recycling of the metal. Certain types of work activities generate large amounts of slurries which are discharged in a river or in the sea.

Examples of industries or products which may be of concern are given in Table 1, together with the typical range of radionuclide concentrations for the dominant radionuclides.

4.2. Approaches to the identification of industries

The regulatory control of practices starts with the responsibility of the undertaking to notify the planned practice to the authorities. Work activities in most cases already operate under specific (non-nuclear) licences and thus the work activity is in principle known to the authorities, as well as its general characteristics. The Basic Safety Standards lay on the national authorities the responsibility for identifying which industries are of concern.

The identification will in general proceed first on the basis of types of industries, secondly on the basis of the origin of the ores or the activity of the feed material, or the enhanced concentration in parts of the process.

In cases where all the information is available, the authorities may identify industries immediately. In many cases however, the authorities need information to be provided by the undertaking. For that purpose the authorities may introduce a reporting requirement similar to that for practices (Title III), or make specific requests on a case-by-case basis.

A reporting requirement would relate to decisions whether a work activity would enter a control regime. For identified work activities, the disposal of radioactive substances, or the recycling or reuse of materials containing radioactive substances, may be subject to prior authorisation. In general, the regulatory approach will be that the authorities identify work activities simultaneously taking into account the disposal of residues, and authorise or immediately exempt both the operation of the industry and the disposal of residues, in particular where the processing of residues in view of reducing the discharges of radioactivity is technically or economically not possible.

In some cases the authorised release of residues, for controlled pathways of recycling or reuse, may be the most appropriate regulatory approach.

4.3. Options

Criteria for reporting or for the identification of work activities on the basis of the activity concentration would in general make reference to defined concentration levels. Where in the case of practices (exemption and clearance levels) the uncertainty on the derivation of such levels is in general small compared to the broad range of activity concentrations which may occur in the practice, this may not be the case for NORM materials in work activities, since the natural variability in ore concentrations is limited and concentration factors cannot be extremely high. Hence an approach based on levels may be very sensitive to the choice of the level, and a certain degree of judgement and pragmatism will need to be applied.

This fact determines the choice among different options available for the identification of the industries on the basis of activity concentrations. The two main options considered in this document are on the one hand the identification by the authority on the basis of *reference levels*, on the other hand the reporting by industries to the authorities on the basis of the activity in the feed material or in later stages of the process *(exemption)* or in the residues *(clearance)*.

The distinction is made for the sake of clarity, but the authorities may consider a scheme which incorporates features of the two options.

Table 1: Examples of industries for which materials with enhanced concentrations of naturally occurring radionuclides may be of concern

Industry/product	Radionuclides and typical activity concentrations
Phosphate industry (fertiliser production) Phosphoric acid (detergents and food)	By-product gypsum: 1kBq kg-1 Ra226 High concentrations of Ra (100kBq kg-1) may precipitate in the plant (scales)
Sulphuric acid production	Pyrites: slag containing > 1kBq kg-1
Coal mine de-watering plants	Sludge may contain 50-100 kBq kg-1 (disposal)
Coal and fly-ash	Fly-ash: typically 0.2 kBq kg-1 U, Th Levels up to 10 kBq kg-1 have been reported in special circumstances. Re-use of fly-ash as construction material
Metal production: smelters	Activity may concentrate in slags and furnace dusts. Re-use of waste (~ 100 kBq kg-1)
Magnesium/Thorium alloys	Up to 4% Th in final alloys. Typically 20% Th in the master alloy
Rare earths: processing of monazite sands, etc	Rare earth ores for cerium, lanthanum, etc: up to 10 kBq kg-1 U, up to 1000 kBq kg-1 Th. Activities in waste streams and dusts may be very high
Foundry sands	Zircon sands (1-5 kBq kg-1) Monazite sands (up to 1000 kBq kg-1)
Refractors, abrasives and ceramics	Zirconium minerals: 5kBq kg-1 U, 1 kBq kg-1 Th
Oil/gas industry	Radium in scales (normally 1-100 kBq kg-1, but up to 4000 kBq kg-1), possibly also Th and daughters (up to 50%)
Ti02 pigment industry	Feed material: ilmenite and rutile ores: 1kBq kg-1 U, Th; waste streams up to 5 kBq kg-1
Thoriated welding rods and gas mantels	Thoriated welding rods: up to 500 kBq kg-1; Th Gas mantels: thorium oxide 95%
Porcelain teeth	Up to 0.03% U
Optical industry and glassware	Rare earth compounds (e.g. cerium) in some polishing powders: Th, U. Some glassware up to 10% of U or Th. Ophthalmic glass for eyeglasses and eyepieces: added U or Th for tinting. Some optical lenses: up to 30% of Th; some lens coating materials

5. Principles for the Application of the Concepts of Exemption and Clearance for Work activities according to Title VII Basic Safety Standards

5.1. Reference levels of activity concentration

The Commission launched a study on the "Establishment of reference levels for regulatory control of workplaces where materials are processed which contain enhanced levels of naturally occurring radionuclides". The Article 31 Group of Experts adopted a Guide on the basis of this work (Radiation Protection No. 95). It provides *reference levels* for identifying those industries for which workers exposure should require regulatory control. The reference levels are specified in terms of activity concentrations of the input material. The exposure scenarios are based on a review of relevant industries within the EU and consider both prudently realistic and unlikely, or extreme, situations.

The reference levels have been defined in relation to marker points in terms of annual effective dose, the key points being those discussed in Chapter 3.2 (1 mSv and 6 mSv per year).

Materials containing NORM usually have a mixture of different radionuclides. Therefore, it was necessary to introduce some method of simplification. For screening purposes a fixed radionuclide composition is assumed and the activity of the input material is characterised on the basis of its single most significant nuclide.

Where a more detailed analysis of the radionuclide composition of the material is available, a more accurate dose estimate can be made using reference levels calculated for all the common radionuclides.

The Guide provides assistance to Member States in identifying the processes where the potential exists for significant radiation exposure of workers.

The screening and categorisation procedures set out in this Guide should not be applied to the more complex, though equally important aspect of exposure of members of the public arising from these industries.

5.2. Exemption and clearance

The schedule of administrative requirements of reporting and prior authorisation, part of Title III, may in certain cases be found useful. There should be no misinterpretation however with regard to the exemption levels referred to in Article 3 of the Basic Safety Standards: these were derived for moderate scale use of artificial radionuclides and are a priori not applicable to naturally occurring radionuclides (except where they are processed in view of their radioactive, fissile or fertile properties).

Where clearance levels are applied the material may enter other premises which potentially could be identified as a work activity. If the latter is subject to exemption values, these should logically not differ from the clearance levels, at least if the same criteria are used and if the different work activities can be covered by a single set of enveloping scenarios. Moreover, in the case of work activities, the amounts of material to be considered are in general very large both for exemption and for clearance, contrary to practices for which clearance often relates to much larger volumes than exemption. Thus for work activities the concepts of exemption and clearance converge and where appropriate the same levels should be used for naturally occurring radionuclides.

5.3. Dose Criterion

In addition to the above conceptual difference between exemption-clearance for natural radiation sources and for artificial sources, the definition of values for natural sources cannot proceed on the basis of the trivial risk criteria established in Annex I of the Basic Safety Standards. For work activities, individual annual exposures may be much higher than 10 µSv and collective doses can be very important. If one would impose a restriction of 10 µSv it would in general not be practicable to implement a control scheme for such a small increment to the natural radiation background, in fact below the natural variability. Exemption-clearance levels for naturally occurring radionuclides should thus be set at a higher dose level than for practices.

The Article 31 Experts propose to set the criteria for exemption-clearance for work activities at an annual effective dose increment of 300 µSv. This can be translated in terms of activity concentrations of (groups of) radionuclides using enveloping scenarios.

The choice of this criterion is justified on the following grounds:

- It is comparable to or smaller than regional variations in total effective dose from natural radiation background (external exposure only)[6].

- It is coherent with the exemption level proposed for building materials (in RP 112).

- It is coherent with any dose constraint which may usefully be considered for the control of effluents (300 µSv recommended by ICRP for practices, a higher value up to 1 mSv being probably more appropriate for work activities).

- It is below the lower marker point for workers exposure proposed for the control of workers exposure in work activities, for the definition of reference levels.

The considerations above allow the introduction of a regulatory control scheme for natural radiation sources which is coherent with existing legislation or guidance (see chapter 3).

The dose criterion of 300 µSv should be regarded as an increment to the exposure which would prevail in the absence of the work activity. In some cases the materials resulting from the work activity shield exposure to the existing background radiation, and this can be allowed for. In other cases the exempted materials replace natural materials also containing background levels of radioactivity. In the case of building materials it would seem appropriate to substract a suitable reference level for the background activity[7].

Even though the individual dose criterion for exemption-clearance of work activities is much higher than for practices, the authorities may nevertheless judge that the *general criteria* for exemption are satisfied, in particular criterion 2 (a) of Annex I of the Basic Safety Standards ("the radiological risk … is sufficiently low as to be of no regulatory concern"). The second criterion 2 (b) can be deemed to be satisfied if, disregarding the 1 man Sv criterion, the authorities judge that exemption is the optimum option (3 (b)).

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6 B.M.R. Green, J.S. Hughes, P.R. Lomas, *Radiation Atlas - Natural Sources of Ionizing Radiation in Europe*, Final Report by NRPB for the Commission of the European Communities, 1993, EUR 14470, ISBN 92-826-4840-0

7 It should be noted that in the guidance on building materials (Radiation Protection 112), the exemption level is an increment of 300 µSv compared to outdoor exposure, while it is proposed here to apply the criterion as an increment to a default value for the indoor exposure.

For the third criterion (2 (c)) it can in general easily be demonstrated that there is "no appreciable likelihood of scenarios that could lead to a failure to meet the criteria in (a) and (b)". Work activities intrinsically cannot give rise to extremely high exposures: even elevated concentrations of radioactivity are low by comparison to most artificial sources. In addition, while for practices it is not allowed to mix or dilute contaminated materials if this would be a means of circumventing requirements for confinement of radioactive waste, for naturally occurring radionuclides one can argue that in most cases dilution or dispersion is nothing more than re-establishing the original natural concentration of the ore.

The more relaxed regulatory approach for work activities has been said to be incoherent with the strict control of practices. The difference in the approaches reflects the higher potential risk from practices on the one hand, and the high variability of the normal range of exposure to natural radiation sources on the other hand. The release from regulatory control of artificial sources is meant to yield nothing but negligible exposures. In the case of work activities, a negligible exposure to natural radiation sources is not quite meaningful and levels of radioactivity are adequate if they correspond to acceptable levels of exposure.

These qualifications, taken from the terminology of ICRP publication-60, also seem to correspond well to the perception and expectation of members of the public.

5.4. Coherence of general clearance with other legislation and guidance

Radon in workplaces

As stated in chapter 3.2, radon concentrations in workplaces below 500 Bq m^{-3} are de facto excluded from the overall exposure. In line with the guidance on building materials, radon in dwellings is taken into account only if the reference level for future concentrations (200 Bq m^{-3}) is exceeded. Thus general clearance/exemption levels have been calculated on the basis of exposure scenarios without radon, and it has been checked subsequently whether the corresponding radon concentrations are below 200 Bq m^{-3} in dwellings and 500 Bq m^{-3} in workplaces.

Reference levels of activity concentration

The above approach for dealing with radon concentrations arising from NORM materials has not been applied when calculating reference levels for the identification of industries by the regulatory authority[8]. Reference levels calculated for the marker points corresponding to 1 mSv (normal assumptions) and 6 mSv (unlikely assumptions) would be higher than exemption/clearance levels for comparable scenarios given that in the latter case the calculation is based on the 300 µSv criterion. This is desirable since otherwise the authorities would have the task of identifying industries which are not subject to the requirement of reporting. For Ra-226 this is not always the case however, since the possible presence of radon in workplaces up to 500 Bq.m^{-3} could add a dose of up to 3 mSv, hence above the 1 mSv marker point.

Such inconsistencies are not dramatic since the reference levels are merely a tool for the authorities, not a regulatory constraint. The additional burden on the authorities is only temporary: as soon as it is confirmed that radon concentrations are below 500 Bq.m^{-3} and residual doses are assessed then they will be so low as not to warrant regulatory control.

8 Radiation Protection 107, J.S.S. Penfold, S.F. Mobbs, J.P. Degrange, T. Schneider, *Establishment of reference levels for regulatory control of workplaces where materials are processed which contain enhanced levels of naturally-occurring radionuclides*, Luxembourg, 1999, ISBN 92-828-6655-6.

Building materials

NORM materials from regulatory control may be reused as building materials. Except for phosphogypsum it has been assumed that there would be a certain dilution in order to meet the technical specifications of the building material. It may seem incoherent that materials are cleared in excess of the index value for exemption of building materials from trade restrictions. There is in that case a certain responsibility of the manufacturers to ensure compliance with the index through an appropriate mix of materials.

This responsibility may seem contrary to the idea of clearance. However, it is not different from the manufacturer's responsibility to check natural materials that are components of the final product. That means, for the final building the principles as given in RP 112[9] must be applied.

Drinking water

In chapter 2.5 it was explained that all public drinking water supplies are regularly checked for the presence of natural radionuclides. This would preclude exposure relating to this pathway beyond 100 μSv (Council Directive 98/83/EC). For the sake of simplicity it has been decided not to include this pathway for compliance with 300 μSv.

The Directive does not apply to private wells however. In most Member States it would not be permitted to drill wells for drinking water in proximity to a landfill. Hence this pathway has been ignored, but it must be highlighted that in regions where this situation does arise, or is liable to arise, that Member States monitor either the radioactivity in landfills or in well water.

In such cases where a public water supply might be contaminated, even if this would not result in exposure of members of the public, this may constitute a detriment to the water supplies and hence the question of liability for the resulting cost should be addressed.

The contamination of groundwater has been included in the scenarios where the water is used for irrigation purposes.

It is concluded that in a number of situations the possibility of drinking water contamination would require a case-by-case analysis, which may seem contrary to the idea of general clearance.

5.5. Background subtraction

For certain external exposure scenarios it is necessary to allow for the shielding of background material (e. g. soil). This depends on the scenario (geometry, replacement of natural building materials, …) and on the reference taken for the background concentration in the soil and in the replaced materials. In order to maintain uniformity of the clearance levels, expressed as total activity (background + enhanced), it has been decided to use the UNSCEAR values for background subtraction.

The procedure for background subtraction (i. e. background dose reduction) is described more detailed in the Annex, chapter 4.1.4 and the chapters dealing with the relevant scenarios.

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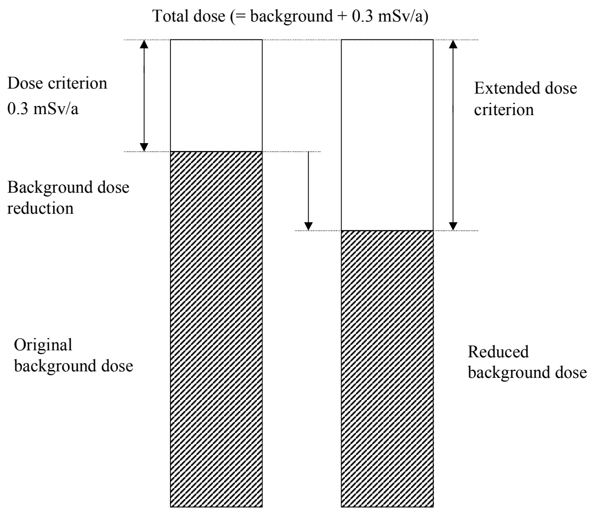
9 See footnote 2.



Scheme for the application of the concept of background dose reduction

It is recognised that this approach, while preserving harmonised values, may cause problems in regions where the local background is very much higher than the UNSCEAR reference. It would not seem appropriate that in such cases one could import high background materials from other parts of the world that could not be processed elsewhere. On the other hand one could not prohibit the processing of local materials. It is concluded that in such regions the application of the general clearance levels be subject to a case-by-case analysis.

5.6. Collective dose

For specific or general clearance of artificial radionuclides it has been demonstrated that the available amounts are such that the collective dose is less than 1 man Sv. For NORM materials the amounts can be very large and hence one should consider collective doses. It should be noted that also the unprocessed ores would give rise to important collective doses over the long time spans that could be considered. It is concluded that for NORM materials the benefit of their use and processing outweighs the radiation detriment, and that it is sufficient to put a constraint on individual dose. Exemption and clearance is considered to make best use of regulatory resources and thus the optimisation requirement is fulfilled.

6. General clearance and Exemption levels (for Work Activities according to Title VII Basic Safety Standards)

6.1. Principles

In case of general clearance the destination of the material is not defined. This means that recycling, reuse or disposal of the materials is possible following clearance, and consequently these possibilities must be taken into account when deriving the clearance criteria. It must be ensured that the levels for *general* clearance are equal to or more restrictive than *specific* clearance levels for different options.

In many cases a prior definition of the destination of the material is not sought or not possible, and cases occur in practice in which the destination or further treatment after clearance cannot be determined with sufficient reliability. For this reason it is of importance to define levels for general clearance and exemption which are valid for a large class of materials and for all possible destinations.

The radiological model for general clearance and exemption must therefore account for all pathways of radiation exposure. For the purpose of deriving general clearance and exemption levels, *enveloping scenarios and parameter values* were developed on expert opinion for the combined exposure paths: ingestion, inhalation, and external γ-radiation. In each case the most restrictive of the enveloping scenarios was adopted and the mass specific activity resulting in 300 μSv/a was used to define the radionuclide-specific clearance level.

The Annex of this document gives a more detailed explanation how such enveloping scenarios were constructed.

Below the general clearance and exemption levels there are in principle no constraints. However, inexpensive actions may sometimes reduce doses even further. The responsible agent for the waste or material entering the clearance procedure should demonstrate that he has chosen an optimum option.

The considerations above are focused on radiation protection. In the case of very low level radioactive materials, it is obvious that health aspects other than radiation may be prominent, like chemical toxicity (industrial waste). Management of the materials should comply with the specific, relevant regulations. Chemical risk may be well above the radiological risk. In the management of radioactive waste where other kinds of health risk, such as chemical are present, the choice of the appropriate option of management should be made by balancing the severity of the different types of risks, radioactive or other, which are involved.

6.2. Dose Calculations

The entire sequence of calculations proceeds along the following lines:

- choice of scenarios
- pathways of exposure
- choice of parameter values
- calculation of individual doses per unit activity concentration (per unit surface concentration for direct reuse)
- identification of the limiting scenario and pathway
- reciprocal individual doses yield activity concentrations corresponding to 300 μSv/a.

In nearly all practical cases more than one radionuclide is involved. To determine if a mixture of radionuclides is below the clearance level a simple summation formula can be used:

$$\sum_{i=1}^{n} \frac{c_i}{c_{Li}} \leq 1.0$$

where

c_i is the total activity in the structure per unit mass of radionuclide *i* (Bq/g),

c_{Li} is the clearance level of radionuclide *i* (Bq/g),

n is the number of radionuclides in the mixture.

In the above expression, the ratio of the concentration of each radionuclide to the clearance level is summed over all radionuclides in the mixture. If this sum is less than one the material complies with the clearance requirements. It is worth noting that this is a conservative approach since the pathways of exposure or the reference group of exposed individuals is not necessarily the same for each nuclide. In many cases it will be useful to identify a measurable indicator nuclide within the spectrum and apply correspondingly a sum-index as defined above to the clearance level for that nuclide.

6.3. Table of General Clearance and Exemption Levels

The derivation, calculation results and discussion for the calculated values are presented in detail in the Annex of this document.

Those nuclides for which the progeny is already accounted for in the dose calculations are marked as in the BSS with the sign "+" to indicate that the derived clearance level also includes daughter nuclides. If such a nuclide is present only as decay product the daughter nuclides listed in Table 6 of the annex need not be considered separately for clearance.

In Table 2 the recommended rounded general clearance and exemption levels for all types of material are given. A different rounding procedure was adopted than the one used in other cases (exemption levels, specific and general clearance levels for practices) mainly for the following reasons:

The dose criterion of 300 µSv should not be exceeded so as to be close to the dose limit;

The generic scenarios for NORM work activities are for the limiting cases more robust than for practices;

The distribution of activity concentrations in NORM industries is not very broad (compared to radioactive waste from practices) so that the economic implications of rounding upwards or downwards are far more important.

While searching for a suitable rounding procedure it was concluded that rounding to significant digits 1 and 5 was preferable to a stricter logarithmic scale (e.g. 1, 3, 10).

Those values that matter indeed happen to be close to 0.5 or 5. The rounding procedure is therefore the following:

$7.07 \,.\, 10^{n-1} < x < 2.24 \,.\, 10^{n} \rightarrow 1 \,.\, 10^{n}$

$2.24 \,.\, 10^{n} \leq x \leq 7.07 \,.\, 10^{n} \rightarrow 5 \,.\, 10^{n}$

Table 2: Rounded General Clearance Levels in kBq/kg

Nuclides*	All materials	Wet sludges from oil and gas industry
*U 238sec incl. U 235 sec***	0.5	5
U nat**	5	100
Th 230	10	100
Ra 226+	0.5	5
Pb 210+	5	100
Po 210	5	100
U 235sec ***	1	10
U 235+ ***	5	50
Pa 231	5	50
Ac 227+	1	10
Th 232sec	0.5	5
Th 232	5	100
Ra 228+	1	10
Th 228+	0.5	5
K –40	5	100

* For radionuclides considered to be in secular equilibrium see table 6 of the annex
** U 238sec and U 235sec are in their fixed natural ratio (99.275 and 0.72 % atomic fraction)
*** Separate values for radionuclides of U 235 series are given here only for information. For NORM these values are never limiting as U 238 and U 235 are always in their fixed natural ratio.

An additional column in Table 2 gives the (considerably higher) values only applicable for wet sludges from the oil and gas industry. The general clearance and exemption values for all materials are very much lower than those for wet sludges from oil and gas industry, essentially because the suspension/inhalation pathway can be ignored. Thus for this type of material it is permitted to use specific values. This is the case however only as long as the material is in the configuration envisaged in the related scenarios (see Annex). If the material dries out, the lower values should apply. This implies some form of engineering or regulatory control which is not strictly compatible with the idea of clearance. It should be noted that the values do not apply either to sludges from other industries in particular where these are discharged with liquid effluent.

7. ANNEX TO RADIATION PROTECTION 122 – PART II CALCULATION OF EXEMPTION/CLEARANCE LEVELS FOR NORM PREPARED FOR THE ARTICLE 31 WORKING GROUP "CONCEPTS OF EXEMPTION AND CLEARANCE"*

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carried out under support of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

1. FOREWORD

Nearly all materials contain certain amounts of “natural” radionuclides from the decay chains of U 238, U 235, Th 232 as well as the natural radionuclide K 40. In several industrial branches, materials with enhanced levels of natural radioactivity are handled, processed, transported or stored in large amounts, the radioactivity itself being of no relevance to the industrial process at all.

Naturally Occurring Radioactive Material (acronym NORM) the activity of which is enhanced by industrial processes is sometimes referred to as TENORM (*Technically Enhanced NORM*) in literature. Here it is also referred to as *NORM*.

The radionuclide contents of these materials may lead to radiological consequences for workers or for the general public. Moreover, in some processing steps the radionuclides are concentrated thus also increasing the radiological importance of the resulting products or waste materials, and in many cases very large quantities of material are involved.

Therefore, over the last years attention has focussed on these materials and on the radiological consequences for the general public, as well as on workplaces where such material is handled, processed or treated. In certain exposure situations where people come into close and prolonged contact with those materials or will inhale dusts generated from it, the resulting dose commitment may be relevant to involve the regulatory authorities. Special consideration has to be given to radon and its decay products.

Radiation protection requirements in the Member States of the European Union (EU) are established at a national level, whereby national legislation is bound by the Euratom Treaty to comply with the EU Basic Safety Standards (BSS) [EUR 96A]. The BSS address NORM in Title VII which is entitled “Significant Increase in Exposure due to Natural Radiation Sources”. Furthermore, the Commission has published specific recommendations concerning NORM [EUR 97A], [EUR 99C]. Title VII of the BSS sets out a separate, flexible control regime for protecting workers and members of the public against exposure from natural radiation sources arising from working activities. With regard to the implementation of the Basic Safety Standards the handling of NORM as an unintentional action in carrying out industrial processes is becoming a major issue of national regulations in the EU member states.

According to Article 40, these regulations shall “apply to work activities not covered by Article 2 (1) within which the presence of natural radiation sources leads to a significant increase in the exposure of workers or of members of the public”, i.e. those work activities, which are not already regulated because of the involvement of artificial sources. The BSS, however, do not provide further quantitative guidance on NORM, they do not contain numerical exemption levels. It must be emphasised that the exemption levels of Annex I Table A of the BSS are not a priori suitable for application to NORM because they are derived only for moderate quantities (a few Mg) of material.

A suitable framework for derivation of exemption / clearance levels for NORM is presented in this document.

2. INTRODUCTION

2.1. Objectives of radiological protection

The BSS leave it to the discretion of the member states of the EU to identify which natural radiation sources need attention and have to be subject to control. The member states further have to set up appropriate means for monitoring exposure and have to ensure application of radiation protection measures as indicated in Article 41 of the BSS. From this it can be concluded that the upper dose level for members of the public of 1 mSv/a according to Article 13 BSS would also be applicable to NORM.

The Article 31 Group of Experts has provided extensive guidance on the identification of workplaces and appropriate measures to protect the workers (e.g. [EUR 97A], [EUR 99C]). Investigations on behalf of the European Commission [EUR 99B] clearly indicate that no uniform and commonly applicable numerical exemption levels could be found that would be valid for all kinds of workplaces and materials. Numerical exemption levels therefore only make sense if they are available for each category of workplace or industry or for each product or waste category. This is a major difference between NORM and artificial sources for which the generally applicable, nuclide specific exemption levels of table A of the BSS are available.

The relevant industrial process steps concerning NORM and its radiological consequences may be defined as followed:

- exploration of raw materials including transport and intermediate storage;
- industrial processing and further refining of the materials and usage of the products;
- management of by-products, production residues, wastes.

All of the above mentioned steps in the production cycle lead to exposure situations. For a radiological assessment, these exposure situations have to be identified for workplaces and/or for members of the general public and calculations have to be made in order to link the activity contents in NORM with the possible dose to persons.

The radiological situation caused by NORM concerning work places (including treatment and storage of raw material and products) is within the scope of many studies performed on behalf of the EC or on behalf of the competent authorities in the member states of the EC (e.g. [EUR 97B], [EUR 99B] [EUR 00], [SSK 97], [TÜV 91], [TÜV 93], [TÜV 94], [TÜV 95], [THI 99]). Handling, processing, use and disposal of NORM residues and waste resulting from these industrial processes and the further waste management as well as its radiological consequences especially for members of the general public has not yet been assessed so widely and is therefore dealt with in this document. The scope of the radiological assessment is as follows:

- workers and members of the general public coming into contact with NORM (no specific workplace scenarios);
- development of exemption/clearance levels based on the radiological assessment of relevant exposure pathways for NORM;

- calculations based on a dose criterion for members of the general public and for workers of 0.3 mSv/a;
- scenarios being based on common recycling and disposal options for industrial NORM residues;
- distinction between the following material types:
  - waste rock,
  - ash,
  - sand,
  - slag,
  - sludge from the oil/gas industry;
- the scenarios do not apply to the discharge of radioactive substances with air or water, nor to intervention cases and the remediation of former mining sites.

A set of realistic but enveloping exposure scenarios was chosen. As far as necessary, material type specific aspects have been taken into account. These radiological scenarios are not intended to describe extremely conservative exposure situations which, however, cannot be excluded to arise in isolated cases. The scenarios correspond to the common recycling- and disposal options for NORM residues. Some of the exposure scenarios defined in the following are valid only for members of the general public. Other scenarios refer to the handling and treatment of NORM with exposure situations both for workers *and* members of the general public (e.g. disposal on a landfill or heap).

Workplaces not belonging explicitly to the NORM processing industrial branches are not treated as controlled workplaces where an increased level of exposure to natural radiation would be authorised. Because of this, these workplaces are dealt with together with scenarios for the general public. Typical examples for such workplaces are belonging to the transportation and storage branch as well as road or house construction. According to this, workers who come into contact with NORM residues inadvertently, are treated as members of the general public with regard to the radiological assessment performed here.

The scenarios analysed in this report correspond to typical recycling and disposal options for NORM residues and are listed according to these two waste management options below. Additionally, the reference group of persons exposed by the scenarios (worker and/or members of the general public) are named in brackets.

<u>Recycling:</u>

- transport over long/short distances (workers)
- storage of moderate quantities, indoors (workers)
- storage of large quantities, outdoors (workers)

- road construction with NORM material (workers)
- building construction with NORM containing building materials (workers)
- building construction using undiluted NORM as unshielded surface cover (workers)
- NORM as surface layer on public places/sports grounds (members of the general public)
- person living in a house with NORM containing building materials (members of the general public)
- person living in a house where undiluted NORM as unshielded surface cover is used (members of the general public)

Disposal:

- transport over long/short distances (workers)
- disposal on a heap or a landfill (workers)
- person living in a house near a heap or landfill (members of the general public). This scenario also includes staying in the garden and on the heap or landfill and secondary ingestion by the groundwater pathway.

As outlined in the main part of this document, a reduction of the background dose can occur when a certain NORM material is used as replacement for the original material (or part thereof). This effect is taken into account in the derivation of clearance/exemption levels as described in section 4.1.4.

2.2. Structure of this Annex

This document is divided in two major parts. In the first part a short overview of the literature is given concerning the radionuclide contents in various NORM. The second part contains an overview of the scenarios and parameters used for the radiological assessment. Based on this data, nuclide specific exemption/clearance levels for bulk quantities of residual material from the non-nuclear industry are calculated. For this purpose specific scenarios are developed, which describe the following exposure situations:

- transport of material: workers;
- storage of material: workers;
- disposal in a landfill or on a heap: landfill operators and people dwelling near the landfill or heap;
- recycling as additive in building material: workers and members of the general public living in the house;
- recycling as filling material in road construction: workers and members of the general public staying on public places.

3. GENERAL ASPECTS CONCERNING NORM

3.1. Data Base Concerning NORM

Many studies which provide data on the radioactivity contents of NORM are available. Some of these studies are evaluated in this section in order to provide an overview of the broad range of material types and their characteristics:

- general survey concerning NORM as a residue of production processes in different industrial branches;
- identification of relevant NORM residue types (physical and chemical properties, typical mass streams per product output);
- activity content, distribution of activity in product/residue;

In addition to the quantities of NORM residues of industrial production processes, the material pathways, the further use of the material, and details of possible exposure scenarios which apply for the various steps of recycling or disposing of the material are important for the radiological assessment.

3.2. Characterisation of the types of NORM residues considered

3.2.1. General aspects

In this section, the general types of NORM considered in this document are characterised. The following general types of material are considered:

- waste rock
- ash
- sand
- slag
- sludge from the oil/gas industry

In general it should be stated, that the assignment of a specific NORM residue to one of the material type groups defined above, can be difficult with regard to the characteristics of the material. The reason is, that the wide spectrum of mechanical, chemical and thermal industrial processes strongly influence the characteristics of the NORM residues. For example, the firing of hard coal can result in types of fly ashes, which are completely different with regard to their grain size spectrum (inhalation pathway) or their leachability (groundwater pathway).

In the course of this document, some typical and generic characteristics of the materials considered are presented, but it should be kept in mind, that in cases of individual radiological assessments specific data are required.

3.2.2. Waste rock

Extraction and processing of the ores and minerals can lead to residues with enhanced levels of radioactivity. Waste rock material in general is characterised by lower dust concentrations than sand and ash. Some examples for materials characterised by the type "waste rock" are presented in Table 1.

Table 1: Activity concentration in waste rock type NORM

NORM residue	**Activity concentration [Bq/kg]**		**Reference**
	U 238 chain	**Th 232 chain**	
rock residues from hard coal mining	60	no data	[TÜV 94]
rock residues from extraction of lead/zinc	< 48	no data	[TÜV 94]
monazite	$2 \cdot 10^4$	$1.5 \cdot 10^5$	[EUR 96B]
zircon	5000	500	[TÜV 94]
phosphorite, CIS	390	25	[TÜV 94]
phosphorite, Marocco	1740	33	[TÜV 94]
raw phosphate, granulated	670	25	[TÜV 94]
gypsum from phosphorite production (raw material: phosphorite)	518	19	[TÜV 94]
gypsum from phosphorite production (raw material: apatite)	56	18	[TÜV 94]
red sludge from alumina production with bauxite	260-537	341-496	[SOR 84]
bauxite	50-500	50-500	[TÜV 94]
rutile	700	200	[EUR 96B]
ilmenite	1500	1000	[EUR 96B]

3.2.3. Ash

Ash is a residue resulting from thermal processing of NORM materials. An important residue of the ash-type with regard to annual production rates are ashes from coal-firing plants.

Fossil fuels also contain primordial nuclides. Mining of coal brings the activity to the surface. After the combustion of coal the greater part of the activity remains in the ash.

A complex system for industrial recycling options and accompanying quality guidelines concerning the quality of the recycling product is already established as an own industrial branch. Activity concentrations for NORM residues of the ash-type are presented in Table 2.

Table 2: Activity concentration in ash type NORM

NORM residue	Activity concentration [Bq/kg]		Reference
	U 238 chain	Th 232 chain	
ash from combustion of hard coal	100	80	[TÜV 94]
ash from combustion of brown coal	70	70	[TÜV 94]
REA* gypsum	2	0.6	[TÜV 94]
ash from incineration plant for domestic waste	5	<2	[TÜV 94]
filter dust in blast furnace iron/steel-production	Pb 210: 12.000		[DRI 98]
ash from lead production	100-300		[TÜV 93]

* REA = "Rauchgas-Entschwefelungs-Anlage" meaning "gypsum from a flue gas desulphurating process"

3.2.4. Sand

The material type "Sand" is characterised by a higher dust concentration than rock and slag material. Of great importance is the extremely low leachability of this material type. Activity concentrations for NORM residues of the sand-type are presented in Table 3.

Table 3: Activity concentration in sand type NORM

NORM residue	Activity concentration [Bq/kg]		Reference
	U 238 chain	Th 232 chain	
zircon sand (e.g. in foundries)	2500-4000	600-700	[KEM 93], [TÜV 93]
mineral sands (monazite)	30-1000	50-300	[BMU 92]

3.2.5. Slag

It is common practice to recycle the slag from industrial processes like steel-making (by processing of iron ore as a primary process) or other processes of non-iron metallurgy like copper-making. The slag is mostly used as aggregate in road building or building projects where, for technical reasons, it is usually mixed with other building materials. A complex system for industrial recycling options and accompanying quality guidelines concerning the quality of the recycling product is already established as a specific industrial branch. Activity concentrations for NORM residues of the slag-type are presented in Table 4.

Table 4: Activity concentration in slag type NORM

NORM residue	Activity concentration [Bq/kg]		Reference
	U 238 chain	Th 232 chain	
iron slag from blast furnace process in iron production	Ra 226: 64-380	Th 232: 30-98	[FGE 99]
slag from steel production	5-31	0-5	
copper slag from primary process	U 238: 35	Th 232: 13	[RÖM 87]
copper slag from secondary process	17	15	[KRÜ 99]
aluminium slag (from secondary production)	12-16	6-9	[BMU 92]
tin slag	Ra 226: 1.100	Th 232: 300	[EUR 99B]
phosphor slag (thermal process)	Ra 226: 1.000	Th 232: 50	[EUR 96B]
slag from incineration plant for domestic waste	18	15	[PUC 99]
lead slag	270	36	[SAA 90]

3.2.6. Sludge from the oil/gas industry

Radon enters natural gas in the geological formation by diffusion from radium deposits. At the well the radon is transported along with the natural gas into the piping system to the consumers. Beside the gaseous radon, water with dissolved salts and solid materials such as sand, are also transported to the surface. These substances are separated from the gas in processing units, forming sludges and fixed scales. The deposits contain radium and the decay products of radon. The concentration of radon varies considerably, depending on the reservoir conditions underground.

The production of sludge by an oil well is more than ten times higher than for a gas well. The volume of sludge is thickened before disposal by about a factor of five.

The volume of radioactive waste produced per unit of product is rather low. However, the huge amounts of primary fossil fuels which are produced, give in total a not insignificant volume of waste at the production sites. An estimate for the total EU could be 10,000 m^3/y [EUR 96B]

Typical activity concentrations for waste from the oil/gas industry are presented in Table 5. The activity concentrations presented for residues resulting from the exploration of oil and gas as well as the estimated mass streams show a great variability.

Table 5: Examples for NORM residues characterised by the material type "sludge from oil/gas industry"

NORM residue	Activity concentration [Bq/kg]	General remarks	Reference
Exploration of oil			
scales (hard deposits)	Ra 226: 27,500 - 39,000 Ra 228: 18,800 - 33,500 Pb 210: 100 – 300	sample from Statfjord B, Norway	[LYS 98]
crud	Ra 226: 2,400-24,200 Ra 228: 1,500-18,800 Pb 210: 200	sample from Statfjord B, Norway	[LYS 98]
sand	Ra 226: 300-5,500 Ra 228: 200-3.700 Pb 210: < 200	sample from Statfjord B, Norway	[LYS 98]
sludge	Ra 226: 100-4,700 Ra 228: 100-4,600 Pb 210: 300-700	sample from Statfjord B, Norway	[LYS 98]
scales (hard deposits)	Ra 226: 9,000-9,800 Ra 228: 8,800 Pb 210: 300	sample from Gullfaks A, Norway	[LYS 98]
sand	Ra 226: 1,100-21,900 Ra 228: 1,100-12,700 Pb 210: 100	sample from Gullfaks A, Norway	[LYS 98]
scales	Ra 226: 4,000-7,700 Ra 228: 7,600-12,400 Pb 210: not measured.	sample from Veslefrikk, Norway	[LYS 98]
scales (Ba/SrO_4, PbS) from oilfield	Ra 226: 59,000 Ra 228: 240,000	installations in Germany	[EUR 99B]

NORM residue	Activity concentration [Bq/kg]	General remarks	Reference
Exploration of gas			
scales (Ba/SrO_4) from natural gas field	Ra 226: 350,000 Ra 228: 7,400	installations in Germany	[EUR 99B]
scales (Pb, Ba/SrO_4) from natural gas field	Ra 226: 160,000 Ra 228: 120,000 Pb 210: 30,000	installations in Germany	[EUR 99B]
deposits (SiO_2, PbS, Hg) from natural gas field	Ra 226: 7,400 Ra 228: 5,900 Pb 210: 70,000	installations in Germany	[EUR 99B]
scales from natural gas field	Ra 226: 1,000,000 Ra 228: < 10,000 Pb 210: 22,000	installations in Germany	[EUR 99B]
scales ($CaCO_3$) from natural gas field	Ra 226: 850 Ra 228: not detectable Pb 210: 1,400	installations in Germany	[EUR 99B]

4. Generic exposure scenarios for the radiological assessment

4.1. General Aspects

4.1.1. General approach to calculation of exemption/clearance levels for NORM

NORM can originate from many different types of industrial production processes. Each process will lead to typical NORM residues with certain physical and chemical properties as well as different activity concentrations. The recycling and disposal options depend on the type and origin of the material as well. The goal of creating exemption/clearance levels which are valid for this wide range of material properties and radiological characteristics means that a certain amount of pessimism must be included in the selection of the parameters. Each industrial branch has its own set of characteristics such as material characteristics (especially activity level), material quantity and preferred waste management option.

The radiological analysis is in general based on large amounts of material. The authorities should be aware that these exemption/clearance levels may therefore be overly restrictive in particular when the NORM mass streams are small. On the other hand the authorities should also be aware that multiple facilities at the same site are likely to use the same waste management strategy which could lead to larger quantities being treated in the same way.

In order to relate the dose received by individuals to a specific practice, or to the levels of radioactivity involved in a practice, a set of exposure scenarios, which relates the activity content to an individual dose is constructed. The strategy is to develop a set of simple but enveloping and realistic scenarios which represent average exposure situations to the critical groups. Exemption/clearance levels for a material category are derived by dividing the dose criterion by the calculated dose (per kBq/kg) from the most restrictive scenario for this material category. The scenarios depend on the following:

- disposal or recycling option;
- intermediate handling (transport) and storage;

- workers[10] and members of the general public;

- type of material;

- external exposure to gamma emissions, inhalation of dust containing radioactivity and ingestion of material;

- inhalation of radon: depending on the exposure situation, the radon concentration in air (Bq/m³) is calculated and is compared to the level of 200 Bq/m³ [EUR 90] for members of the public and 500 Bq/m³ [EUR 97A] for workers, respectively;

- groundwater pathway: dispersion of radionuclides via seepage from e.g. a heap or a landfill to a groundwater layer and from there to a private well is taken into account by assuming that the groundwater is used for irrigation of crops.

It is important for the derivation of scenarios to bear in mind that material which is at one time recycled will later become waste which might be disposed of (in a landfill or on a heap). Disposal at a later time is fully covered by the disposal scenarios, because any disposal after an initial reuse or recycling will lead to further mixing which will reduce the specific activity. The other option: to recycle material after it has been disposed of is not explicitly taken into account in the scenarios. This recycling would, however, be covered by the recycling scenarios which could be applied in cases where material from disposal sites or heaps will be recycled once again.

4.1.2. Radionuclides

Table 6 lists the nuclides and decay chains to be considered here. The U 238 chain is assumed to be in natural equilibrium with the U 235 chain.

Table 6: Summary of nuclides and chain segments that are used in modelling

Parent	Nuclides considered in secular equilibrium
Uranium decay chains*	
U 238sec	U 238, Th 234, Pa 234m, Pa 234 (0.3%), U 234, Th 230, Ra 226, Rn 222, Po 218, Pb 214, Bi 214, Po 214, Pb 210, Bi 210, Po 210
U nat**	U 238, Th 234, Pa 234m, Pa 234 (0.3%), U 234, U 235 (4.6%), Th 231 (4.6%)
Th 230	Th 230
Ra 226+	Ra 226, Rn 222, Po 218, Pb 214, Bi 214, Po 214
Pb 210+	Pb 210, Bi 210
Po 210	Po 210
U 235sec	U 235, Th 231, Pa 231, Ac 227, Th 227 (98.6%), Fr 223 (1.4%), Ra 223, Rn 219, Po 215, Pb 211, Bi 211, Tl 207, Po 211 (0.3%)
U 235+	U 235, Th 231
Pa 231	Pa 231
Ac 227+	Ac 227, Th 227 (98.6%), Fr 223 (1.4%), Ra 223, Rn 219, Po 215, Pb 211, Bi 211, Tl 207, Po 211 (0.3%)

10 workers are understood in this context as special members of the general public, not as controlled workers

Parent	Nuclides considered in secular equilibrium
Thorium decay chain* **	
Th 232sec	Th 232, Ra 228, Ac 228, Th 228, Ra 224, Rn 220, Po 216, Pb 212, Bi 212, Po 212 (64.1%), Tl 208 (35.9%)
Th 232	Th 232
Ra 228+	Ra 228, Ac 228
Th 228+	Th 228, Ra 224, Rn 220, Po 216, Pb 212, Bi 212, Po 212 (64.1%), Tl 208 (35.9%)
K 40	
K 40	K 40
* U 238 series and U 235 series considered in secular equilibrium (and radionuclides which may be relevant for some industrial processes leading to separation, e.g. Th 230 and Ra 226, or volatilisation, e.g. Pb 210 and Po 210) ** Natural U or U nat corresponds to the three uranium isotopes in their fixed natural ratio. Due to the short half life of their daughters they are included also in the calculations. *** Th 232 series considered in secular equilibrium (and radionuclides which may be relevant for some industrial processes leading to separation, e.g. Ra 228)	

With regard to the activity concentrations of the NORM residues the following assumptions are made as a basis for the dose calculations:

- In general it is assumed that inside the NORM residues the radionuclides of the natural decay chains are in secular equilibrium. Therefore all activity concentrations given in section 3 are for each nuclide of the corresponding decay chain (if not stated differently). Because of this it is generally not necessary to use a summation rule for the nuclides of a particular decay chain (with exception of the enhancement process in the partial chain Pb 210, Bi 210, Po 210, see below). When the equilibrium between nuclides of one decay chain is disturbed, the data on activity concentrations refer to the nuclide with the highest individual activity.

- An important special situation with regard to practical industrial processes is the transfer of Pb 210/Po 210 to the flue gas stream of thermal processes and the enhancement of these nuclides in ashes and dust in the filter systems. This disturbed equilibrium may be of radiological concern with regard to the disposal of filter ashes from coal-fired plants. For these materials, the dose calculations are performed additionally for the partial chain Pb 210/Bi 210 and Po 210 under the assumption that no increased activity concentrations of other radionuclides of the U 238 decay chain are present. For the radiological assessment of the NORM material itself, in this case a sum formula has to be used, because the activity concentrations of the other nuclides of the U 238 decay chain may be lower than the concentrations for the partial chain Pb 210, Bi 210, Po 210 but nevertheless not neglectable.

- The mechanical, chemical and thermal processing procedures used in NORM processing industry do not cause a shifting of the natural isotope relation between U 238 and U 235 in the material considered. The dose contributions of these nuclides are considered in the results for the U 238 chain according to the natural isotope relation between U 238 and U 235. The specific activity of the nuclides of the U 235-chain amount to 4.6 % of the specific activity of the nuclides of the U 238 chain. Therefore the results of the dose calculation for the U 235 chain are only given for information and not for practical use.

- Doses caused by nuclides of the U 238 and Th 232 decay chain can arise independent of each other. In the case of enhanced activity concentrations of nuclides of both chains, a summation rule has to be used in order to calculate the total dose.

Carbon-14 and long lived rare earth isotopes are not included.

4.1.3. Potassium 40

A special situation with regard to the dose calculations is represented by the incorporation of K 40, which is not considered in the frame of the radiological assessment in this study. The reason is, that according to expert opinion (see for example [SCH 98]), the significant further uptake of Potassium via drinking water or food is not possible, when the level necessary for the organism of the reference person is reached. Therefore, also no radioactive Potassium 40 can be taken up under this condition. Additionally, the inhalation dose to the lungs can be neglected due to the relatively low dose coefficient. For these reasons, the dose calculations for Potassium 40 are limited to the exposure pathway external irradiation.

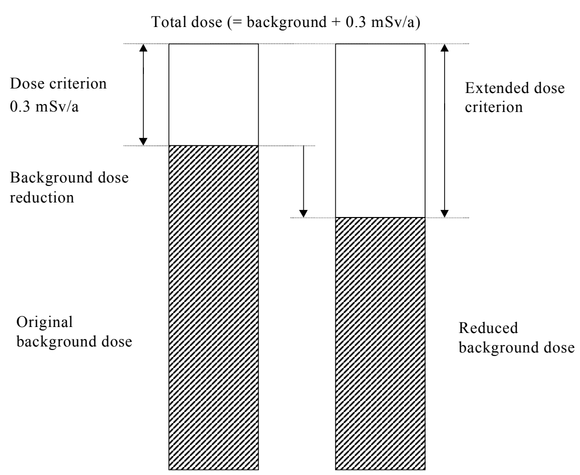
4.1.4. Background dose reduction

Because of the application of cleared NORM the background dose could be reduced. The background dose is reduced when whole or part of the original material is replaced by the cleared material (for instance: sand in concrete is replaced by cleared sand or natural gypsum is replaced by phosphogypsum) or when the applied NORM material shields the terrestrial background, which would be present in the absence of the cleared NORM. The dose reduction is mostly due to reduced external radiation, but also reduction of internal doses from inhalation or ingestion of background concentrations of natural radionuclides may occur.

In all cases the background dose from average background concentrations in the natural material is reduced by that fraction of the material which is replaced by the cleared NORM.

For reasons of calculation this reduction may be compensated by extending the dose criterion, which is chosen at 0.3 mSv per year, so the *total dose* (background plus dose criterion) remains unchanged. In Figure 1 this concept is shown graphically.

Figure 1 Scheme for the application of the concept of background dose reduction



The background dose reduction is calculated for the average concentrations of the Uranium (U 238sec), Thorium (Th 232sec) and K 40 concentrations in natural materials (obtained from UNSCEAR report 1988 for soil [UNS 88] and for different building materials and rocks [EUR 99A], [EUR 99C].

First the total background dose reduction is calculated using the scenario parameters but applied to the average natural concentrations instead of unity concentration. Then the dose criterion is extended with the total background dose reduction. This extended criterion is then used to calculate the clearance values for each radionuclide separately.

The application of this approach with regard to each exposure scenario as well as the values for background activity concentrations (in kBq/kg), substractable doses (in mSv/a) and the resulting extended dose criterion for all material types as applied to the derivation of the exemption/clearance levels are presented in the tables of the scenario descriptions in sections 4.2 and 4.3.

4.1.5. Multiple exposure of reference persons

A further basic aspect of radiological assessments is the consideration of multiple exposure of a certain reference person, caused by superposition of different scenarios. Here, multiple exposures are not considered, which can be explained with regard to the following arguments:

- The scenarios chosen already offer a high grade of conservatism, which would lead to an overestimation of doses for the reference person when taking into consideration multiple exposures (e.g. a warehouse worker, who is exposed by stored NORM residues during his working time and is also living in a house built with NORM containing building material).
- The exemption / clearance levels derived here are based on a dose criterion of 0.3 mSv/a, which also allows the possibility of multiple exposures yet being in compliance with the radiological protection goals of the Basic Safety Standards.

4.1.6. Scenario independent parameters

Scenario independent parameters for workers are:

- The annual working time, which is assumed to be 1800 h/a: Given a 37.5 hour week and 44 weeks a year (6 weeks leave plus public holidays), the normal working hours amount in total to about 1650 h/a. This shows that the assumed working time of 1800 h/a is covering for the workers.
- The breathing rate, which was chosen as 1.2 m^3/h for workers according to ICRP for light exercise.
- The direct ingestion rate is set to 10 mg/h which corresponds to ca. 18 g/a on the basis of 1800 h/a working time. This ingestion rate is in accordance with scenarios considered in [SSK 98], [IAE 00], [EUR 98].

For the scenarios considered for members of the general public, parameters dependant on the age group of the reference person as defined in the BSS have to be taken into account. These parameters refer to the inhalation pathway (breathing rates), the direct ingestion pathway (ingestion rate for dust) and the secondary ingestion pathway via irrigation with contaminated groundwater and food consumption. Consumption of drinking water from a private well has not been included in the scenarios (see chapter 6.3). The parameters and corresponding values are in Table 7.

Table 7: Scenario independent parameters for members of the general public

Parameters	Units	Age of reference person according to BSS [EUR 96A]					
		0-1 a	1-2 a	2-7 a	7-12 a	12-17 a	> 17 a
Inhalation pathway							
Breathing rates	m^3/h	0.12	0.22	0.36	0.64	0.84	0.925
Ingestion pathways							
Ingestion rate for dust	g/h	0	0.01	0.01	0.005	0.005	0.005
Consumption rates (leafy vegetables)	kg/a	0	5	10	15	17	20
Consumption rates (other vegetables and fruit)	kg/a	5	25	50	75	85	100
fraction of food bought on market	[-]	0.5					
preparation reduction factor for food	[-]	0.5					
further parameters are provided together with the scenario description in section 5.5.2							

4.1.6.1. Dilution factor

The term recycling – as opposed to reuse – is understood to mean the use of substances as secondary raw material for the manufacture of new materials or new products. An important example of this is the recycling of NORM residues to make building materials. During the manufacturing process the substances are usually mixed with uncontaminated materials, with the result that in the end product there is almost always a reduction in specific activity compared with the NORM residue material. Such processes must be thoroughly investigated for their radiological impacts in this study.

In all radiological scenarios in the scope of this study, it is considered, whether the NORM residue can be used as a recycling material without dilution, whether it can be used only as an additive to uncontaminated material or cannot be reused at all. This strongly depends on the type of NORM material.

The demands on the product as laid down in various guidelines on product quality concern characteristics like mechanical strength, structure of the surface or other physical and chemical demands (e.g. in the case of building materials with NORM residues). The result of these demands on the quality of the products containing NORM residues are dilution factors, which represent a technological upper limit for the content of NORM residues in the products.

The dilution factors represent the content of NORM residues in the material, which causes the radiological exposure and are therefore taken into consideration with regard to the dose calculations.

The derived exemption/clearance levels (in kBq/kg) in the frame of the radiological assessment are understood as exemption/clearance levels for the activity concentration of the NORM residue itself and not for the material which contains a certain amount (according to the dilution factor) of NORM residue. For example: The derived exemption/clearance level refers to the NORM fly ash contained in a certain type of building material and not to the certain type of building material itself. For this reason the resulting values can be higher than the ones given in [EUR 99A].

As already mentioned, the dilution factors for the recycling options of NORM residues as caused by technical demands, are considered in the dose calculations performed in this study.

For slags as additive in building material, a dilution factor of 0.3 is used; for ashes this factor is reduced to 0.1. These values correspond to typical upper limits for NORM additives in concrete production. In isolated cases, for the content of slag in building material higher values are also possible (e.g. slag stone), but these building materials are usually not used on a large scale or represent only a small part of the building structure.

Therefore the defined dilution factors used here for the dose calculations are enveloping for most practical cases of usage.

4.1.6.2. Dust concentrations

In general a dust concentration corresponding to an annual average value is used for the dose calculations. In many cases, this average dust concentration was derived on the basis of a high and a normal value for the dust concentrations together with the corresponding duration of time. A high dust concentration characterizes working procedures like for example road construction and disposal on a landfill, where large amounts of NORM material are handled.

A "normal" dust concentration characterizes situations without dust intensive working procedures in close physical proximity. In general, during the handling and treatment of NORM rock and slag material (except for crushing), the arising dust concentrations are lower than for the other material types investigated in the frame of this radiological assessment (sand/ash).

Inside a building (reference person living in a house), a lower concentration of suspended dust than outside the house was chosen. The values for the dust concentrations are provided in the course of the scenario descriptions.

4.1.6.3. Activity concentration factor in the fine grain fraction

The effect of enhanced concentration of activity in the fine grain fraction in comparison to the average activity concentration of the material was taken into account.

For the inhalable fraction, a concentration factor in the dust of 2 for material of the type "rock/earth" or "ash" and a value of 1 for all other considered types of materials was chosen.

For the ingestable fraction of NORM material (< 0.5 mm) a concentration factor of 1 was chosen, for all material, assuming that the NORM materials considered are all characterised by a nearly homogenous activity distribution in the corresponding grain size spectrum.

4.2. Enveloping exposure scenarios for workers

This section describes scenarios (exposure conditions) for people who are working with or transporting NORM but who are not part of the NORM industry. This distinction is important with regard to the relevant dose criteria underlying the radiological assessment for the reference person.

4.2.1. Transport – Long distances

4.2.1.1. General description of the exposure situation

A truck driver transports NORM residues from place A to its destination at place B, which can be a landfill, a road construction or a mill where the material is processed for the preparation of concrete or other building material. It is assumed, that the transport is carried out mainly over longer distances and that the truck drives back empty. The duration of the scenario is therefore estimated at a total exposure time of 850 h/a for driving and 100 h/a for loading and unloading procedures. The load of NORM residue is not diluted with uncontaminated material (i.e. dilution: 100%). The parameters for sludge type residues from oil and gas industry differ mainly because the involved quantities are much smaller (see Table 8).

The exposure is predominantly by external radiation, comprising shielding. During loading and unloading the driver is exposed to dust, therefore the exposure pathway inhalation has to be taken into account. The duration of the exposure is relatively short but with a high dust load which is assumed to be at an average level of 1 mg/m³. It is assumed that the sludges from the oil and gas production are transported in closed containers or drums. Therefore internal exposure pathways are not considered.

4.2.1.2. Exposure pathways and parameters

External exposure

For loading and driving, a geometry for the load characterised by a block with the following dimensions was assumed: 2 m width, 2 m height, 5 m length. With a density of the material of 1.5 g/cm³ the resulting total weight of the load is 30 Mg.

During driving of the truck, the external exposure distance to the driver is 1 m and a total shielding structure of 1 cm of steel is assumed, which consists of the cabin, the loading compartment and the seat. During loading and unloading procedures, the exposure distance to the block of load as described above is also 1 m and no shielding is assumed.

The exposure time during driving is 850 h/a and during loading and unloading procedures is 100 h/a. For materials from the oil and gas industry the transport is carried out in closed drums.

Inhalation of dust

Inhalation of dust is assumed only for loading and unloading procedures. The dust concentration is set to 1 mg/m³. This value characterizes an annual average for dusty working procedures. The exposure time is 100 h/a and the breathing rate for the reference person (truck driver) during loading and unloading is set to 1.2 m³/h. This value is according to ICRP and valid for light exercise. For material from the oil and gas industry no inhalation is assumed because the material is transported in closed drums.

Ingestion

The ingested quantity is 10 g/a, according to an annual exposure time to the NORM residues of about half a working year (850 h for driving, 100 h for loading and unloading) based on the ingestion rate of 10 mg/h. For material from the oil and gas industry no ingestion is assumed because the material is transported in closed drums.

Background dose reduction

In the absence of cleared NORM the truck driver can transport any type of material, thus also with zero natural radioactivity. Therefore background dose reduction is not considered in this scenario.

Overview of the parameters used for dose calculations

Table 8 shows the relevant parameters for the dose calculations for the transport scenarios.

Table 8: Parameters for both transport scenarios

Parameters	Units	Rock	Ash	Sand	Slag	Sludge (oil/gas)
General parameters						
dilution	%	100%	100%	100%	100%	75%
density	kg/m^3	1500	1500	1500	1500	1500
exposure time driving long distances	h/a	850	850	850	850	85
exposure time loading (long distances)	h/a	100	100	100	100	10
exposure time driving short distances	h/a	700	700	700	700	70
exposure time loading (short distances)	h/a	400	400	400	400	40
Parameters for external γ-dose						
geometry	[-]	”truck”: 2 x 2 x 5 m^3, 30 Mg total, shielding,				material in closed drums
height	m	2	2	2	2	
width	m	2	2	2	2	
length	m	5	5	5	5	
Parameters for inhalation dose						
dust concentration	mg/m^3	1	1	1	1	0
breathing rate	m^3/h	1.2	1.2	1.2	1.2	-
Parameters for ingestion dose						
direct ingestion	mg/h	10	10	10	10	0
Parameters for background dose reduction						
Background dose reduction is not considered						

4.2.2. Transport – Short distances

4.2.2.1. General description of the exposure situation

This working scenario describes a truck driver, who transports NORM from place A to B driving back the empty truck, mainly over short distances. The exposure time amounts to 700 h/a for driving and 400 h/a for loading and unloading procedures. For transport of sludges from the oil and gas production over short distances the exposure times are 70 h/a and 40 h/a respectively.

The other assumptions are similar to the transport scenario described before.

4.2.3. Storage – Moderate quantities, indoors

4.2.3.1. General description of the exposure situation

This working scenario describes exposure situations, which can arise during the indoor storage of moderate quantities in a ware-house. The radiological exposure assessed here is caused by the stored material itself, which is not diluted with uncontaminated material (dilution factor 100%). The storage area is 1000 m²; the volume of the storage room is assumed to be 4000 m³. The exposure time for a worker in this ware-house is a full working year of 1800 h/a.

4.2.3.2. Exposure pathways and parameters

<u>External exposure</u>

The storage area inside the ware-house amounts to 1000 m². The geometry of the stored NORM material resembles a truncated cone with a height of 3 m, 45° angle. This heap is characterised by the following measures:

- Radius base: 11.86 m
- Height: 3 m
- Area top: 246 m²
- Area side: 195 m²
- Total area: 441 m²

The bulk volume of the NORM material amounts to 1000 m³. In the course of carrying out the working tasks, the reference person (warehouse worker) has an average distance from the edge of the heap with NORM material of about 5 m. No shielding is assumed, because bulk material normally is stored without packaging. Material from the oil and gas industry is stored in closed drums.

<u>Inhalation</u>

The indoor storage of bulk material results in elevated dust concentrations, especially during loading or turn over of the material.

Concerning the dust concentrations, two cases referring to the operation of the warehouse are distinguished:

- procedures with processing of the material: here an indoor dust concentration of 2 mg/m³ is chosen for all NORM materials except for sludge from the oil/gas industry;
- processing of sludge: for instance, de-watering or the removal of mercury and organic substances by vacuum distillation yields a dry residue, which will be put in an intermediate storage before it is transferred to a disposal site. Dust concentrations are chosen as 1 mg/m³ but exposures are only for a short time due to the small quantities that will be processed annually.

- procedures without processing: here an indoor dust concentration of 0.5 mg/m^3 is chosen for rock and slag, 1 mg/m^3 is chosen for ash and sand and 0 mg/m^3 for sludge from the oil/gas industry.

The breathing rate is 1.2 m^3/h, corresponding to ICRP (light exercise).

For sludge from the oil and gas industry no inhalation is assumed because the material is stored in closed drums.

<u>Ingestion</u>

The ingestion rate of 10 mg/h was used for a time of 1800 h/a. For sludge from the oil and gas industry no ingestion is assumed as long as the material is stored in closed drums. In cases of processing, an ingested quantity of 10 mg/h is assumed as for the other material types.

<u>Background dose reduction</u>

In the absence of cleared NORM the warehouse can be used to store any type of material (also material with zero radioactivity). Shielding of the terrestrial radiation is only valid when the person is standing on the heap, which is not the case in this scenario. Therefore background dose reduction is not considered here.

<u>Overview of the parameters used for dose calculations</u>

Table 9 shows the relevant parameters for the dose calculations for the indoor storage scenario.

Table 9: Parameters for storage of moderate quantities indoors

Parameters	**Units**	**Rock**	**Ash**	**Sand**	**Slag**	**Sludge (oil/gas)**
General parameters						
dilution	%	100%	100%	100%	100%	75%
density	kg/m^3	1500	1500	1500	1500	1500
exposure time	h/a	1800	1800	1800	1800	1800 (ext.) 180*
Parameters for external γ-dose						
geometry	[-]	1000 m^3, height 3 m , 45° angle, truncated cone, reference person: 5 m distance from base				storage in closed drums
Parameters for inhalation dose						
dust concentration with processing procedures	mg/m^3	2	2	2	2	1
dust concentration without processing procedures	mg/m^3	0.5	1	1	0.5	0
breathing rate	m^3/h	1.2	1.2	1.2	1.2	1.2
Parameters for ingestion dose						
direct ingestion	mg/h	10	10	10	10	10* 0**
Parameters for background dose reduction						
Background dose reduction is not considered						
* for inhalation and ingestion; with processing ** for inhalation and ingestion; without processing						

4.2.4. Storage – Large quantities, outdoors

4.2.4.1. General description of the exposure situation

This scenario describes the storage of NORM material in large quantities outdoors. The NORM material is not diluted with uncontaminated material (dilution factor 100%). Such an exposure scenario may for example be relevant in the case of storage of NORM in an industrial area (yard of a NORM processing company). The exposure time for a worker at this area is 1800 h/a.

This scenario is not applicable for residues from the oil and gas industry because of the small quantities produced.

4.2.4.2. Exposure pathways and parameters

External exposure

The geometry of the heap stored outdoors is characterised by the following measures:

Volume 10,000 m^3, height 6 m, 45° angle, the resulting surface of the heap can be calculated from a truncated cone geometry as 2127 m^2.

The average distance of the reference person (worker) from the edge of the heap is 10 m; no shielding is assumed.

Inhalation

The inhalation of dust is calculated using a set of values for dust concentrations, which takes into account two operational situations for the storage:

dust concentrations with processing of the material: In this case, a value of 1 mg/m^3 for all materials was chosen.

dust concentrations without processing of the material: In this case, 0.2 mg/m^3 for rock/slag and 0.5 mg/m^3 for ash/sand was chosen.

A breathing rate of 1.2 m^3/h for the reference person was assumed.

Ingestion

An ingestion rate of 10 mg/h for the whole working year was assumed.

Background dose reduction

Shielding of the terrestrial radiation is only valid when the person is standing on the heap, which is not the case in this scenario. For this reason background dose reduction is not considered here.

Overview of the parameters used for dose calculations

Table 10 shows the relevant parameters for the dose calculations for the storage of large quantities outdoors.

Table 10: Parameters for storage of large quantities outdoors

Parameters	Units	Rock	Ash	Sand	Slag	Sludge (oil/gas)
General parameters						
dilution	%	100%	100%	100%	100%	-
density	kg/m³	1500	1500	1500	1500	-
exposure time	h/a	1800	1800	1800	1800	-
Parameters for external γ-dose						
geometry	[-]	10.000 m³, height 6 m , 45° angle, truncated cone, reference person: 10 m distance from base				-
Parameters for inhalation dose						
dust concentration with processing procedures	mg/m³	1	1	1	1	-
dust concentration without processing procedures	mg/m³	0.2	0.5	0.5	0.2	-
breathing rate	m³/h	1.2	1.2	1.2	1.2	-
Parameters for ingestion dose						
direct ingestion	mg/a	10	10	10	10	-
Parameters for background dose reduction						
Background dose reduction is not considered						

4.2.5. Disposal on a heap / landfill

4.2.5.1. General description of the exposure situation

This scenario describes exposure situations for workers at a landfill site and comprises the disposal of NORM residues at the landfill as well as working procedures in the course of the operation of the landfill (for example profiling of the surface, covering of filled up areas of the landfill and usage as approach to the landfill). Also exposure situations caused by filling procedures in open-cast-working areas and during the construction of slopes may be characterised by this scenario.

It is assumed that a worker spends approximately 1800 h/a working time on the landfill spreading and levelling deposited NORM residues.

With regard to the dilution of the NORM material on the heap/landfill, two cases are distinguished:

- disposal of large NORM amounts: in this case it is imaginable, that the heap/landfill serves only for the disposal of this specific type of NORM material (for example disposal as a heap in the yard area of a company processing NORM); the dilution factor is assumed to be 100%

- disposal of small NORM amounts: bulk material normally is disposed of on large landfills/heaps. Therefore the small amounts characterised here may be diluted with uncontaminated material (for example disposal on a public landfill). The dilution factor is chosen as 10%.

In most cases waste is delivered to landfill sites by truck. The waste is unloaded from the truck and then incorporated into the landfill site. Typical disposal rates for individual workers (or work teams consisting of a few workers) range from 20 to 50 Mg/h ([DEC 95] and [DEC 97]). An assumed disposal rate of 20 Mg/h and the assumed working time of 1800 h/a yields a disposal rate per reference worker (or work team) on the heap/landfill of 36,000 Mg/y.

Concerning disposal of processed material from the oil and gas industry, this scenario is only applicable for the disposal of small quantities. Therefore the dilution is set to 1%.

4.2.5.2. Exposure pathways and parameters

External exposure

The exposure of the landfill personnel to external γ radiation is represented by a exposure geometry of a point situated one metre above a semi-infinite volume (large landfill area surrounding the reference person). The worker is shielded by the structures of the vehicle which is used to carry out the levelling and disposal work. A shielding by steel with an overall shielding factor of 2 is assumed.

Inhalation

The working procedures are characterised by high dust concentrations during delivery, unloading and compacting of the waste (typical value of 2 mg/m^3) and by lower dust concentrations during equaalising and profiling work (typical values 0.1 to 1 mg/m^3). Based on measurements on landfill sites, a covering inhalable dust concentration of 1 mg/m^3 is assumed as an annual average (cf. [LFU 94], [DEC 97], [EUR 95]). A breathing rate of 1.2 m^3/h is assumed for the worker.

Ingestion

An ingestion rate of 10 mg/h was chosen for the whole working year of the reference person.

Background dose reduction

By disposal of large amounts of cleared waste on a large heap or in a landfill the external radiation from the underlying soil is shielded completely. Background dose reduction from internal pathways is neglected, since it is assumed that normal dust concentrations from resuspension of undisturbed soil are at a very low level.

For small NORM amounts it is assumed that the NORM is diluted in a landfill consisting of other, non-NORM, waste. The existing background dose at this landfill is the dose from the waste heap itself and not from the underlying soil. Since it is conservative to assume that this waste does not contain natural radioactivity, the corresponding background reduction is zero.

Overview of the parameters used for dose calculations

Table 11 shows the relevant parameters for the dose calculations for the disposal scenario.

Table 11: Parameters for disposal on a heap / landfill

Parameters	Units	Rock	Ash	Sand	Slag	Sludge (oil/gas)
General parameters						
dilution, large NORM amounts	%	100	100	100	100	-
dilution, small NORM amounts	%	10	10	10	10	1
density	kg/m³	1500	1500	1500	1500	1500
exposure time	h/a	1800	1800	1800	1800	1800
Parameters for external γ-dose						
geometry	[-]	semi-infinite volume; shielding by a vehicle (steel, factor 2)				
Parameters for inhalation dose						
dust concentration	mg/m³	1	1	1	1	1
breathing rate	m³/h	1.2	1.2	1.2	1.2	1.2
Parameters for ingestion dose						
direct ingestion	mg/h	10	10	10	10	10
Parameters for background dose reduction (large NORM amounts)						
Background concentration	Bq/kg	Soil: U 238sec: 25, Th 232sec: 25, K 40: 370				
Exposure pathways		external				
Reduced background dose	mSv/a	0.073	0.073	0.073	0.073	-
Extended dose criterion	mSv/a	0.373	0.373	0.373	0.373	-
Parameters for background dose reduction (small NORM amounts)						
Background dose reduction is not considered						

4.2.6. Road construction

4.2.6.1. General description of the exposure situation

The recycling of NORM residues as filling material in road and landscape construction projects is one of the main recycling options especially for NORM residues coming from coal firing plants and from the primary (blast furnace) iron and steel manufacturing industry. This scenario describes exposure situations caused by handling of NORM residues as building material in carrying and covering layers of road construction projects.

The reference road construction worker is occupied his whole working time (1800 h/a) with handling of NORM as building material for road construction.

During the construction phase, a dilution of the NORM material with uncontaminated material has to be assumed because of quality demands on the building materials. For rock and slag material, no dilution is assumed because of the appropriate material characteristics. For ash a dilution factor of 0.1 and for sand a dilution factor of 0.8 was chosen. Concerning material from the oil and gas industry, this scenario is not applicable because this material is not suitable for recycling in road construction.

The radiological consequences during the construction phase in comparison to later repair or demolition works are dominant.

4.2.6.2. Exposure pathways and parameters

External exposure

The working procedures are characterised by high dust concentrations during delivery, unloading and compacting of the waste (typical value of 2 mg/m³) and by lower dust concentrations during equaalising and profiling work (typical values 0.1 to 1 mg/m³). Based on measurements on landfill sites, a covering inhalable dust concentration of 1 mg/m³ is assumed as an annual average.

Inhalation

During the construction works relatively high dust concentrations arise in the course of material deposition and compacting. Other working procedures like for example covering the carrying layers are characterised by lower dust concentrations. Therefore an average annual dust concentration of 1 mg/m³ for all NORM materials considered is chosen. The breathing rate is 1.2 m³/h.

Ingestion

An ingestion rate of 10 mg/h during working hours is assumed for the reference worker.

Background dose reduction

The background dose is reduced because the normal materials (for instance rocks) which are used for road construction are replaced - entirely or partially - by the cleared NORM. The background dose of the road construction worker is due to the pathways external radiation, inhalation and ingestion.

Overview of the parameters used for dose calculations

The following table shows the relevant parameters for the dose calculations for road construction with NORM residues.

Table 12: Parameters for road construction

Parameters	Units	Rock	Ash	Sand	Slag	Sludge
General parameters						
dilution	%	100%	10%	80%	100%	-
density	kg/m³	2000	2000	2000	2000	-
exposure time	h/a	1800	1800	1800	1800	-
Parameters for external γ-dose						
geometry	[-]	plane				
length	m	100	100	100	100	-
width	m	10	10	10	10	-
thickness	m	0.4	0.4	0.4	0.4	-
Parameters for inhalation dose						
dust concentration	mg/m³	1	1	1	1	-
breathing rate	m³/h	1.2	1.2	1.2	1.2	-
Parameters for ingestion dose						
direct ingestion	mg/h	10	10	10	10	-
Parameters for background dose reduction						
Background concentration	Bq/kg	Rocks: U 238sec: 60, Th 232sec: 60, K 40: 640				
Exposure pathways		external + inhalation + ingestion				
Reduced background dose	mSv/a	0.131	0.013	0.105	0.131	-
Extended dose criterion	mSv/a	0.431	0.313	0.405	0.431	-

4.2.7. Building construction with NORM containing building materials

4.2.7.1. General description of the scenario

This scenario describes typical exposure situations during building construction work with usage of building materials containing NORM residues. The radiological assessment only refers to the additional dose which is caused by the NORM additives in the building material.

The chosen dilution factors to characterise the content of NORM residue in the building materials is 30% for rock, sand and slag and 10% for ash.

The exposure time for the worker building the house is 1800 h/a.

Concerning material from the oil and gas industry, this scenario is not applicable because this material is not suitable for use in building construction.

4.2.7.2. Exposure pathways and parameters

External exposure

The enveloping scenario for the external exposure of the reference person is an entire room made of building material with NORM content, in which the reference person is situated for his whole working time. The geometric data for the reference room are described in the table below. The geometry accounts for doors, windows and the use of uncontaminated materials by assuming two (instead of 4 walls) made of NORM containing building material.

Inhalation

Building construction work comprises some dust intensive working procedures like sawing, grinding, mixing. As an annual average value, a dust concentration of 0.5 mg/m³ for all NORM materials is assumed. The breathing rate is 1.2 m³/h.

Ingestion

An ingestion rate of 10 mg/h during working hours is chosen for the reference worker.

Background dose reduction

The background dose is reduced by partial replacement of the constituents of concrete by cleared NORM. The background dose of the building construction worker is due to the pathways external radiation, inhalation and ingestion.

Overview of the parameters used for dose calculations

Table 13 shows the relevant parameters for the dose calculations for building constructions with building material containing NORM material.

Table 13: Parameters for building construction (building material with NORM additives)

Parameters	Units	Rock	Ash	Sand	Slag	Sludge (oil/gas)
General parameters						
dilution	%	30%	10%	30%	30%	-
density	kg/m³	2300	2300	2300	2300	-
exposure time	h/a	1800	1800	1800	1800	-
Parameters for external γ-dose						
geometry	[-]	floor, ceiling, 2 walls (3 x 4 m²), 20 cm wall thickness, 2.5 m height				
length	m	3	3	3	3	-
width	m	4	4	4	4	-
wall thickness	m	0.2	0.2	0.2	0.2	-
Parameters for inhalation dose						
dust concentration	mg/m³	0.5	0.5	0.5	0.5	-
breathing rate	m³/h	1.2	1.2	1.2	1.2	-
Parameters for ingestion dose						
direct ingestion	mg/h	10	10	10	10	-
Parameters for background dose reduction						
Background concentration	Bq/kg	Concrete: U 238sec: 40, Th 232sec: 30, K 40: 400				
Exposure pathways		external + inhalation + ingestion				
Reduced background dose	mSv/a	0.038	0.013	0.038	0.038	-
Extended dose criterion	mSv/a	0.338	0.313	0.338	0.338	-

4.2.8. Building construction using undiluted NORM as unshielded surface cover

4.2.8.1. General description of the exposure situation

The description of the scenarios and most of the parameters are identical to the scenario described above in section 4.2.7 ("building construction with building materials containing NORM"), but with the significant difference that the walls of the house are plated with a layer of gypsum material.

Therefore, the exposure geometry is chosen as follows:

- 3 walls of the reference room in a house covered with gypsum wallplates (thickness 0.02 m), which are assumed to be of the material type ash.

The undiluted use of rock and sand is not imaginable and therefore is not considered here. The undiluted use of slag is imaginable as isolation material (slag-wool), but in this case a shielding of this material by uncontaminated wall covering materials is to be assumed. Therefore also slag is not considered here.

Concerning material from the oil and gas industry, this scenario is not applicable because this material is not suitable for use in building construction.

4.2.8.2. Exposure pathways and parameters

External exposure

The worker is exposed during 1800 h/a to the external radiation of 3 walls of the reference room in a house covered with gypsum wall plates (thickness 0.02 m), which are assumed to be of the material type ash.

Inhalation and ingestion

The inhalation and ingestion pathway is characterised by the same parameters as in the scenario described above.

Background dose reduction

The background dose is reduced by the replacement of natural gypsum by cleared NORM. The background dose of the building construction worker is due to the pathways external radiation, inhalation and ingestion.

Overview of the parameters used for dose calculations

Table 14 shows the relevant parameters for the dose calculations for house construction works with building material consisting of NORM.

Table 14: Parameters for Building construction (building material made of NORM)

Parameters	**Units**	**Rock**	**Ash**	**Sand**	**Slag**	**Sludge (oil/gas)**
General parameters						
dilution	%	-	100%	-	-	-
density	kg/m³	-	1500	-	-	-
exposure time	h/a	-	1800	-	-	-
Parameters for external γ-dose						
geometry	[-]	3 walls (3 x 4 m²), 2.5 m height, covered with gypsum wall plates, thickness 0.02 m				
length	m	-	3	-	-	-
width	m	-	4	-	-	-
layer thickness	m	-	0.02	-	-	-
Parameters for inhalation dose						
dust concentration	mg/m³	-	0.5	-	-	-
breathing rate	m³/h	-	1.2	-	-	-
Parameters for ingestion dose						
direct ingestion	mg/h	-	10	-	-	-
Parameters for background dose reduction						
Background concentration	Bq/kg	Natural gypsum: U 238sec: 10, Th 232sec: 10, K 40: 80				
Exposure pathways		external + inhalation + ingestion				
Reduced background dose	mSv/a	-	0.004	-	-	-
Extended dose criterion	mSv/a	-	0.304	-	-	-

4.3. Enveloping exposure scenarios for members of the general public

4.3.1. NORM additives in building material for public places/sports ground

4.3.1.1. General description of the exposure situation

This scenario describes the recycling of NORM residues as an unfixed surface layer for public places and sports grounds (for example: slag as surface for football pitches) or for roads without fixed surface. Because the exposure time on such roads is assumed to be shorter than on public places and sports grounds and because the areas relevant for exposure are also smaller in this case, the exposure of a reference member of the general public on a public place or sports ground is the enveloping scenario. For the exposure time, it is assumed, that the reference person spends 1.5 h/d on this public place/sports ground, resulting in a total exposure time of about 500 h/a (for children aged 0 - 1 a: 0 h/a).

As building material for this recycling option, NORM rock, sand and slag material can be used undiluted whereas ash material requires mixing with other materials with a dilution factor of 0.1.

Concerning material from the oil and gas industry, this scenario is not applicable because this material is not suitable for use as cover material.

4.3.1.2. Exposure pathways and parameters

External exposure

An infinite plane with a layer thickness of 0.1 m is assumed as irradiation geometry. The reference point is situated 1 m above this plane.

Inhalation

Areas with unfixed surface layer material containing NORM show an elevated dust concentration during driving or walking on it. As an average value during exposure 0.5 mg/m³ is assumed for all NORM-materials considered. The breathing rate depends on the age of the reference person belonging to the group of members of the general public. A description of age-dependent breathing rates is presented in section. 4.1.

Ingestion

The direct ingestion rate depends on the age of the reference person belonging to the group of members of the general public. A description of age-dependent direct ingestion rates is presented in section 4.1.

Background dose reduction

The background dose is reduced because the normal materials (f.i. gravel) which are used for public places and sports grounds are replaced - entirely or partially - by the cleared NORM. The background dose reduction is age dependent due to differences in residence times, respiration and ingestion rates.

Overview of the parameters used for dose calculations

Table 15 shows the relevant parameters for the dose calculations for the exposure of reference persons by surface layer material with NORM on public places/sports grounds.

Table 15: Parameters for public places/sports ground

Parameters	Units	Rock	Ash	Sand	Slag	Sludge (oil/gas)
General parameters						
dilution	%	100%	10%	100%	100%	-
density	kg/m³	2000	2000	2000	2000	-
exposure time	h/a	< 1 a: 0 ≥ 1 a: 500	< 1 a: 0 ≥ 1 a: 500	< 1 a: 0 ≥ 1 a: 500	< 1 a: 0 ≥ 1 a: 500	-
Parameters for external γ-dose						
geometry	[-]	plane, 10 cm thickness				-
length	m	infinite				-
width	m	infinite				-
wall thickness	m	0.1	0.1	0.1	0.1	-
Parameters for inhalation dose						
dust concentration	mg/m³	0.5	0.5	0.5	0.5	-
breathing rate	m³/h	depending on age of reference person				-
Parameters for ingestion dose						
direct ingestion	mg/h	depending on age of reference person				-
Parameters for background dose reduction						
Background concentration	Bq/kg	Gravel: U 238sec: 50, Th 232sec: 50, K 40: 670				
Exposure pathways		external + inhalation + ingestion				
Reduced background dose	mSv/a	0.031-0.036	0.003-0.004	0.031-0.036	0.031-0.036	-
Extended dose criterion	mSv/a	0.331-0.336	0.303-0.304	0.331-0.336	0.331-0.336	-

4.3.2. Person living in a house near a heap/landfill

4.3.2.1. General description of the exposure situation

This scenario describes the radiological exposure of a member of the general public, who is living in a house near a heap or a landfill which is not covered by a shielding layer made of uncontaminated material. For some materials this might be a conservative assumption because a heap usually would require a top layer if recultivation is planned. However, many waste rock heaps do not possess a covering layer. It is assumed that the heap/landfill contains undiluted NORM material of the various types.

Concerning sludges from the oil and gas industry, a dilution of 1% on the heap or landfill was chosen. The other parameters have been chosen in accordance with rock material.

The scenario comprises three exposure situations:

- residence in the house near the heap/landfill;
- staying in the garden belonging to the house and
- staying on the heap/landfill without presence of a covering layer (especially valid for heaps)

The resulting effective doses for these three exposure situations are added.

It is assumed that the reference person spends 6000 h/a in the house, 1000 h/a in the garden near the house and some time on the heap or landfill itself depending on the age of the reference person: 0 h/a for 0-2 a, 250 h/a for 2-12 a, 100 h/a for 12-17 a and adults.

The house is located at a distance of 25 m (on the average) from the edge of the heap/landfill; the garden belonging to the house has a distance of 20 m from the edge of the heap/landfill. For the stay on the heap the dose rate is calculated at a height of 1 m.

Concerning exposure via water pathways, the following scenario is included: water from the heap or the landfill migrates to a groundwater layer and is transported to a private well from which water is taken for irrigation of plants in the garden of the house (for drinking water see chapter 6.3). It is assumed that the well is situated downstream of the heap or landfill site in the groundwater flow.

The post-operational use of the landfill site for example as a residential area is not considered in the frame of this radiological assessment. This is based on the assumption, that there is no loss of control by the authorities over a period of time of about the next 150 years. Under this assumption, it can be concluded that appropriate measures of radiological assessment and sanitation measures of the landfill area will be carried out in order to ensure the radiological protection targets.

4.3.2.2. Exposure pathways and parameters

External exposure

The modelling of the external exposure is based on the following geometry of the heap/landfill: area 100,000 m², height 10 m above ground, length 300 m. The distance from the heap/landfill to the reference person in the garden is 20 m, the distance to the person in the house is 25 m and the distance for the exposure on the heap/landfill itself is 1 m (above ground). The external exposure caused by the heap/landfill is shielded (walls with 20 cm thickness) by the house itself, when the reference person stays inside the house.

Inhalation

Doses caused by dust inhalation are calculated using different dust concentrations at the exposure locations considered:

- on the heap/landfill: 0.2 mg/m³ for rock/slag; 0.5 mg/m³ for ash/sand
- in the garden: 0.05 mg/m³ for rock/slag; 0.1 mg/m³ for ash/sand
- inside the house: 0.02 mg/m³ for rock/slag; 0.05 mg/m³ for ash/sand

The corresponding average breathing rates are age dependent and are chosen as recommended by ICRP, i.e. 0.12, 0.22, 0.36, 0.64, 0.84, 0.925 m³/h for all three exposure situations (house, garden, heap).

Ingestion

Three mechanisms are considered with regard to the calculation of doses caused by ingestion:

- Direct ingestion: residual material is only directly ingested when the reference person stays on the heap. The ingestion rates are age dependant with the following corresponding values: 10 mg/h for 1-7 a and 5 mg/h for 7-17 a and adults.

- Secondary ingestion of vegetables grown in the garden, covered with dust from the heap: The deposition rate for fine dust amounts to 0.001 m/s and the assumed deposition time during growth is 60 d.

- Secondary ingestion via the groundwater pathway: precipitation enters the heap or landfill and leaches the radionuclides from the NORM material. The seepage enters the groundwater layer from where it is mixed with uncontaminated water. Water is taken from the groundwater layer by a private well and used for irrigation. In the garden, leafy and root vegetables and fruit are grown, which are assumed to account for half of the persons annual diet.

The secondary ingestion pathway is calculated with the equation:

$$C_v = D \cdot f \cdot TLF \cdot \frac{(1-\exp(-(\lambda_r + \lambda_w)) \cdot t_a}{Y \cdot (\lambda_r + \lambda_w)} + \frac{D \cdot (1-f) \cdot T_a}{\rho \cdot h} \cdot B_v ,$$

which describes the activity concentration in vegetation after direct deposition on crops (the first term) or via root uptake (second term). The deposition D is calculated as $C_{dust} \cdot v_d$ in case of dry deposition and as $C_w \cdot I$ in case of irrigation, where C_w is the concentration of the well water. Table 16 shows the parameters for calculating the activity concentration in the groundwater layer.

The retention factor f is calculated as f = exp(-μ B), with μ is the interception coefficient and B the biomass (dry weight) per unit area. The remaining parameters are explained in Table 17, which presents the parameters used for calculation of the concentration in the plants following deposition of dust and for the irrigation scenario.

Background dose reduction

The reduction of the normal background from uncovered soil is only considered for the time a person spends on top of the heap, since only in this situation the terrestrial radiation is shielded by the cleared NORM. The contribution to the background dose of internal pathways are also taken into account, since it is assumed that in the absence of NORM the outdoor scenarios also apply for exposure to background concentrations of natural radionuclides.

Overview of the parameters used for dose calculations

Table 16 shows the relevant parameters for the dose calculations for the scenario "living in a house near a heap/landfill". The calculations include the exposure pathways via external radiation, inhalation and direct ingestion. Table 17 presents the parameters used for calculation of the dust concentration on the plants and for the groundwater scenarios. Table 18 shows the parameters for calculation of the activity concentration in the groundwater layer.

Table 16: Parameters for house with garden near heap

Parameters	Units	Rock	Ash	Sand	Slag	Sludge (oil/gas)
General parameters						
dilution	%	100%	100%	100%	100%	1%
density	kg/m³	1500	1500	1500	1500	1500
exposure time house	h/a	6000	6000	6000	6000	6000
exposure time garden	h/a	1000	1000	1000	1000	1000
exposure time heap (0-1 a)	h/a	0	0	0	0	0
exposure time heap (1-2 a)	h/a	0	0	0	0	0
exposure time heap (2-7 a)	h/a	250	250	250	250	250
expos. time heap (7-12 a)	h/a	250	250	250	250	250
expos. time heap (12-17 a)	h/a	100	100	100	100	100
expos. time heap (>17 a)	h/a	100	100	100	100	100
Parameters for external γ-dose						
geometry heap		heap 10 m height, area 100.000 m², 300 m length, above ground				
geometry garden		distance 20 m from edge of heap				
geometry in house		distance 25 m from edge of heap, 20 cm concrete shielding by walls of the house				
heap area	m²	100.000				
heap height	m	10				
Parameters for inhalation dose						
dust concentration on heap	mg/m³	0.2	0.5	0.5	0.2	0.5
dust concentration in garden		0.05	0.1	0.1	0.05	0.1
dust concentration in house		0.02	0.05	0.05	0.02	0.05
breathing rate	m³/h	dependant on age of reference person				
Direct ingestion						
direct ingestion	mg/h	on heap: dependant on age of reference person in garden and house: 0				
Parameters for background dose reduction (only for time spend on heap)						
Background concentration	Bq/kg	Soil: U 238sec: 25, Th 232sec: 25, K 40: 370				
Exposure pathways		external + inhalation + ingestion				
Reduced background dose	mSv/a	0-0.011	0-0.011	0-0.011	0-0.011	0
Extended dose criterion	mSv/a	0.3-0.311	0.3-0.311	0.3-0.311	0.3-0.311	0.3

Table 17: Parameters used for calculation of the ingestion dose by dust deposition and irrigation

Ingestion via dust deposition on plants									
deposition rate of dust	v_d	m/s	0.001						
deposition time	t_a	D	60						
vegetable yield	Y	kg/m²	2						
dry weight fraction of foliage	dw	kg(dw)/kg	0.1						
retention coeff.; dry small particles	µ	m²/kg	3						
retention factor	f		0.45						
translocation factor	TLF	m²/kg	0.1						
activity per kg crop per mg/m³	C_v	Bq/kg	0.07						
ingestion via groundwater pathway/irrigation, deposition on the plants									
irrigation	I	L/(a m²)	100						
deposition time	t_a	D	60						
vegetable yield	Y	kg/m²	2						
dry weight fraction of foliage	dw	kg(dw)/kg	0.1						
retention coeff.; wet large particles	f / B	m²/kg(dw)	0.5						
retention factor	f		0.4						
translocation factor	TLF	m²/kg	0.1						
activity per kg crop per Bq/L		Bq/kg	0.42						
Ingestion via groundwater pathway/irrigation, root uptake									
Irrigation	I	L/(a m²)	100						
Fraction reaching ground	1 - f		0.6						
Years of irrigation	T_a	a	25						
Thickness of root layer	h	m	0.2						
Density of root layer	ρ	kg/m³	1300						
Activity* per kg soil per Bq/L	C_s	Bq/kg	5.8						
Transfer factors for relevant nuclides to vegetables									
			U	Pa	Ac	Th	Ra	Pb	Po
Transfer factors to vegetables	B_v	kg/kg	0.0083	0.0083	0.0083	0.0018	0.049	0.01	0.0012
Activity* per kg crop per Bq/L	C_v	Bq/kg	0.048	0.048	0.048	0.010	0.28	0.058	0.0069
Age dependent consumption rates of vegetables and fruit									
			0–1a	1–2a	2–7a	7–12a	12–17a	> 17a	
leafy vegetables		kg/a	0	5	10	15	17	20	
other vegetables and fruit		kg/a	5	25	50	75	85	100	
* Activity in soil and crops not corrected for radioactive decay									

Table 18: Parameters used for calculating the activity in the groundwater layer

Parameter	Unit	Rock	Ash	Sand	Slag	Sludge
activity	kBq/kg	1				
area of heap	m²	100,000				
mass of heap	Mg	1E+6				
dilution		1	1	1	1	0.01
total activity of heap	Bq	1E+12	1E+12	1E+12	1E+12	1E+10
released fraction per year		0.001	0.0001	0.00001	0.0001	0.001
annual rainfall	m/a	0.8				
infiltration		0.25				
annual seepage	m³/a	20,000				
activity concentr. in seepage	Bq/m³	50000	5000	500	5000	500
depth of aquifer	m	5				
usable pore fraction		0.25				
groundwater velocity	m/a	730				
annual groundwater flow	m³/a	290,000				
radioact. conc. in groundwater per 1 Bq/g in the NORM material	Bq/l	3.2E+00	3.2E-01	3.2E-02	3.2E-01	3.2E-02

4.3.3. Person living in a house built with building material containing NORM

4.3.3.1. General description of the exposure situation

This scenario describes all exposure situations relevant for a member of the general public living in a house, which was built using building material containing NORM (for example fly-ash in the concrete matrix). This scenario comprises do-it-yourself works on the building.

Other sources of natural radiation exposure for example caused by building materials without additives of NORM material but nevertheless with significant content of natural radioactivity (like granite) are not considered in the radiological assessment performed in the frame of this study.

The exposure time in the house is set to 7000 h/a. Because in this case the exposure only takes place in the house and not in the garden or away from the house as in the previous scenario (section 4.3.2), the time of 1000 h/a which was allocated to staying in the garden is added to the time spent in the house (6000 h/a).

With respect to dilution factors, 30% for rock, sand and slag and 10% for ash is chosen for the fraction of the building material consisting of NORM (see also section 4.2.7).

Concerning material from the oil and gas industry, this scenario is not applicable because this material is not suitable for use in building construction.

4.3.3.2. Exposure pathways and parameters

<u>External exposure</u>

The geometry for external irradiation is characterised by an entire room, in which the reference person is situated. By assuming only 2 walls which are constructed with NORM containing building materials, the geometry takes into account, that windows, doors and other parts of the structure are not containing NORM additives.

Inhalation

In general it is not expected that any significant inhalation doses will occur during building occupancy, therefore this pathway is not considered here.

Ingestion

In general it is not expected that any significant ingestion doses will occur during building occupancy, therefore this pathway is not considered here.

Background dose reduction

The background dose is reduced by partial replacement of the constituents of concrete by cleared NORM. Only the reduced background dose from external radiation is taken into account.

Overview of the parameters used for dose calculations

Table 19 shows the relevant parameters for the dose calculations for the scenario " Person Living in a House Built with building material containing NORM".

Table 19: Parameters for house built with NORM additives in building material

Parameters	Units	Rock	Ash	Sand	Slag	Sludge (oil/gas)
General parameters						
dilution	%	30%	10%	30%	30%	-
density	kg/m³	2300	2300	2300	2300	-
exposure time house	h/a	7000	7000	7000	7000	-
Parameters for external γ-dose						
geometry	[-]	floor, ceiling, 2 walls (3 x 4 m²), 20 cm wall thickness, 2.5 m height				-
Parameters for inhalation dose						
no inhalation dose is assumed						
Parameters for ingestion dose						
no ingestion dose is assumed						
Parameters for background dose reduction						
Background concentration	Bq/kg	Concrete: U 238sec: 40, Th 232sec: 30, K 40: 400				
Exposure pathways		external				
Reduced background dose	mSv/a	0.123	0.041	0.123	0.123	-
Extended dose criterion	mSv/a	0.423	0.341	0.423	0.423	-

4.3.4. Person living in a house built with undiluted NORM as unshielded surface cover

4.3.4.1. General description of the exposure situation

The description of the scenarios and most of the parameters resembles the scenario described above ("building construction with building materials containing NORM"), but with the significant difference, that the walls of the house are plated with a layer of gypsum material. Therefore the geometry was chosen as follows:

- 3 walls of the reference room in a house covered with gypsum wallplates (thickness 0.02 m), which are assumed to be of the material type ash (thickness 0.02 m).

Concerning the exposure time of 7000 h/a, the same considerations apply as in the previous scenario (section 4.3.3).

The undiluted use of sand is not imaginable and therefore is not considered here. The undiluted use of slag is imaginable as isolation material (slag wool), but in this case a shielding of this material by uncontaminated wall covering materials is to be assumed. Therefore also slag is not considered here.

Concerning material from the oil and gas industry, this scenario is not applicable because this material is not suitable for use in building construction.

4.3.4.2. Exposure pathways and parameters

External exposure

The geometry for external irradiation is characterised by a room, in which the reference person is situated, consisting of 3 walls plated with gypsum wall plates of 2 cm thickness.

Inhalation

In general it is not expected that any significant inhalation doses will occur during building occupancy, therefore this pathway is not considered here.

Ingestion

In general it is not expected that any significant ingestion doses will occur during building occupancy, therefore this pathway is not considered here.

Background dose reduction

The background dose is reduced by the replacement of natural gypsum by cleared NORM. Only the reduced background dose from external radiation is taken into account.

Overview of the parameters used for dose calculations

Table 20 shows the relevant parameters for the dose calculations for the scenario “Person living in a house built with building material consisting of NORM”.

Table 20: Parameters for house built with NORM building material

Parameters	Units	Rock	Ash	Sand	Slag	Sludge (oil/gas)
General parameters						
dilution	%	-	100%*	-	-	-
density	kg/m³	-	1500	-	-	-
exposure time house	h/a	-	7000	-	-	-
Parameters for external γ-dose						
geometry	[-]	3 walls (3 x 4 m²), 2.5 m height, covered with gypsum wall plates, thickness 0.02 m-				
wall thickness	[m]	-	0.02	-	-	-
Parameters for inhalation dose						
no inhalation dose is assumed						
Parameters for ingestion dose						
no ingestion dose is assumed						
Parameters for background dose reduction						
Background concentration	Bq/kg	Natural gypsum: U 238sec: 10, Th 232sec: 10, K 40: 80				
Exposure pathways		external				
Reduced background dose	mSv/a	-	0.006	-	-	-
Extended dose criterion	mSv/a	-	0.306	-	-	-
* ash: refers to gypsum wall plate						

5. EXPOSURE PATHWAYS

5.1. Dose coefficients

In addition to exemption limits for practices as defined under Title III, the EU Basic Safety Standards 1996 [EUR 96A] also contain age-related dose coefficients for the incorporation paths ingestion and inhalation which are calculated on the basis of Recommendation No. 60 of the International Commission on Radiological Protection (ICRP) [ICR 90]. The dose calculations have been performed with these dose coefficients in [EUR 96A]. To this end the dose coefficients from Table C1 of the EU Basic Safety Standards were used for workers, e.g. landfill workers, whereas the dose coefficients from Tables A and B were used for the general public. The nuclide specific dose coefficients are listed in the appendix.

5.2. Reference person

The Basic Safety Standards [EUR 96A] define 6 age groups for the reference persons (<1 a, 1-2 a, 2-7 a, 7-12 a, 12-17 a, >17 a), which are different with regard to the relevant internal dose coefficients. A separate set of internal dose coefficients is defined for workers. This structure is also considered in this study.

The calculation of radiological doses according to these age groups, the corresponding set of dose coefficients and the derivation of exemption/clearance levels afterwards is based on the following assumptions made in the frame of this study:

- Although in the context of these calculations a worker is understood to be a member of the general public, the inhalation dose coefficients for workers are used since these are based on the specific resperation rates for workers during working conditions. The inhalation dose coefficients used are for 5 micron AMAD dust particles as is recommended by the ICRP.

- In the case of the scenarios, where members of the general public are the reference person, an age group dependant calculation of the total dose for each of the scenarios considered has to be performed. In each case, the derived maximum dose contribution characterises the reference person belonging to this scenario. On the basis of the maximum dose derived with regard to all scenarios in the frame of the radiological assessment, the exemption/clearance level belonging to the NORM material considered is derived.

5.3. External γ-dose

The external γ dose is calculated using the following formula,

$$H_{ext} = D_{ext} \cdot t_e \cdot f_d \cdot f_{dec} \qquad \text{(eq. 1)}$$

where

H_{ext} [(µSv/a)/(kBq/kg)] individual annual dose from external irradiation per kBq/kg,
D_{ext} [(µSv/h)/(kBq/kg)] average dose rate during the exposure year,
t_e [h/a] exposure time
f_d [-] dilution factor
f_{dec} [a] decay time

Table 21 and Table 22 show dose coefficients for the calculation of effective doses caused by external γ-radiation (in (mSv/h)/(kBq/kg)). D_{ext} is calculated using standard software (e.g. Microshield). Here and in all following tables U 238sec and U nat include the contribution of U 235sec resp. U 235+ according to their fixed natural ratio.

Table 21: Dose coefficients for the calculation of effective doses caused by external γ-radiation for worker scenarios (in (Sv/h)/(kBq/kg))

Nuclide	Transport	Small heap	Large heap	Disposal site	Road constr.	Building #1	Building #2
U 238sec	7.72E-08	3.19E-08	3.21E-08	4.31E-07	3.08E-07	5.67E-07	5.33E-08
U nat	7.13E-10	4.50E-10	4.44E-10	6.23E-09	4.23E-09	7.47E-09	9.49E-10
Th 230	1.06E-12	3.82E-12	3.40E-12	3.85E-11	2.78E-11	5.12E-11	9.41E-12
Ra 226+	7.61E-08	3.12E-08	3.14E-08	4.20E-07	3.01E-07	5.55E-07	5.17E-08
Pb 210+	6.08E-20	7.03E-12	2.14E-12	1.07E-10	9.29E-11	8.78E-11	4.01E-11
Po 210	3.54E-13	1.48E-13	1.48E-13	2.07E-12	1.41E-12	2.69E-12	2.63E-13
U 235sec	1.09E-08	8.33E-09	8.40E-09	1.33E-07	8.05E-08	1.45E-07	1.92E-08
U 235+	1.79E-09	2.23E-09	2.25E-09	3.58E-08	2.14E-08	3.73E-08	5.42E-09
Pa 231	5.90E-10	4.19E-10	4.23E-10	6.86E-09	4.04E-09	7.52E-09	9.48E-10
Ac 227+	8.53E-09	5.68E-09	5.73E-09	9.02E-08	5.51E-08	9.97E-08	1.28E-08
Th 232sec	1.18E-07	4.74E-08	4.77E-08	6.21E-07	4.59E-07	8.18E-07	7.33E-08
Th 232	1.86E-13	1.48E-12	1.21E-12	2.23E-11	1.59E-11	3.40E-11	5.35E-12
Ra 228+	4.00E-08	1.66E-08	1.66E-08	2.27E-07	1.59E-07	2.98E-07	2.86E-08
Th 228+	7.79E-08	3.08E-08	3.11E-08	3.94E-07	3.00E-07	5.20E-07	4.47E-08
K 40	7.61E-09	2.86E-09	2.86E-09	3.77E-08	2.89E-08	5.13E-08	4.49E-09

Table 22: Dose coefficients for the calculation of effective doses caused by external γ-radiation for scenarios for the general public (in (Sv/h)/(kBq/kg))

Nuclide	**Playground**	**Outdoors, Heap-20 m**	**Indoors, Heap-25 m**	**Outdoors, on heap 1 m**	**House #1, indoors**	**House #2 indoors**
U 238sec	3.34E-07	5.50E-08	4.47E-09	4.31E-07	5.67E-07	5.33E-08
U nat	5.31E-09	7.55E-10	2.96E-11	6.23E-09	7.47E-09	9.49E-10
Th 230	3.69E-11	5.82E-12	1.11E-14	3.85E-11	5.12E-11	9.41E-12
Ra 226+	3.25E-07	5.37E-08	4.43E-09	4.20E-07	5.55E-07	5.17E-08
Pb 210+	1.07E-10	1.02E-11	1.01E-20	1.07E-10	8.78E-11	4.01E-11
Po 210	1.66E-12	2.53E-13	1.39E-14	2.07E-12	2.69E-12	2.63E-13
U 235sec	1.18E-07	1.45E-08	2.16E-10	1.33E-07	1.45E-07	1.92E-08
U 235+	3.29E-08	3.87E-09	2.11E-11	3.58E-08	3.73E-08	5.42E-09
Pa 231	6.02E-09	7.34E-10	9.95E-12	6.86E-09	7.52E-09	9.48E-10
Ac 227+	7.93E-08	9.93E-09	1.85E-10	9.02E-08	9.97E-08	1.28E-08
Th 232sec	4.62E-07	8.19E-08	8.85E-09	6.21E-07	8.18E-07	7.33E-08
Th 232	2.13E-11	2.21E-12	1.64E-15	2.23E-11	3.40E-11	5.35E-12
Ra 228+	1.78E-07	2.84E-08	1.91E-09	2.27E-07	2.98E-07	2.86E-08
Th 228+	2.84E-07	5.35E-08	6.94E-09	3.94E-07	5.20E-07	4.47E-08
K 40	2.77E-08	4.95E-09	4.90E-10	3.77E-08	5.13E-08	4.49E-09

5.4. Inhalation dose

5.4.1. Inhalation of resuspended particles

Inhalation of resuspended radioactivity can occur in particular through suspension in air during the use, processing or disposal of NORM solids. An inhalation dose can only occur when the activity in the NORM material is re-suspended into the air and someone breathes this dust loaded air. Such a re-suspension will occur when the NORM material is transported, broken up and processed or dumped at a landfill. The inhalation doses are calculated according to scenario dependant age groups, dust concentrations, breathing rates and concentration factors in the fine dust fraction.

The following equation is used to calculate the inhalation doses,

$$H_{inh} = D_{inh} \cdot t_e \cdot B_r \cdot f_k \cdot C_{dust} \qquad \text{(eq. 2)}$$

where

H_{inh} [(Sv/a)/(kBq/kg)] individual dose from inhalation during exposure time,
D_{inh} [Sv/Bq] dose coefficient (table C Euratom Directive, 5 µm),
t_e [h/a] exposure time,
B_r [m³/h] breathing rate,
f_k [-] concentration factor for the activity in the inhalable dust fraction,
C_{dust} [g/m³] effective dust concentration during exposure time

The breathing rates are chosen in accordance to ICRP 66 [ICR 94]. The mass specific concentration of the dust will be higher than for the average NORM itself, since the activity preferably binds to the small particles causing the activity to concentrate in the fine dust fraction [COR 94] [BAK 90]. This activity concentration effect in the fine dust fraction is accounted for in the dose calculations by the factor f_k.

Since it can be expected that large scale road or building construction work will be carried out by workers, the dose coefficients for workers from table C in the Euratom Directive are used. The mass median aerodynamic diameter of the dust particles created during renovation are typically in the range of several micrometers [JOH 94], [HAR 95]. Therefore the most restrictive dose coefficient for an AMAD of 5 µm was chosen for the dose calculations and no correction is made for the particle size distribution.

Although higher dust concentrations may occur for short times in various areas of application, this cannot be expected for the annual average. The long exposure time and the level of the average dust concentration mean that even potential concentration effects are implicitly covered by defining an annual average dust concentration as defined for the scenarios considered here.

The dose coefficients used for the calculations are presented in Table 23.

Table 23: Dose coefficients for inhalation

Nuclide	<1	1 - 2	2 - 7	7 - 12	12 – 17	> 17	worker
U 238sec	1.91E-04	1.66E-04	1.09E-04	7.07E-05	6.15E-05	5.70E-05	2.91E-05
U nat	6.34E-05	5.52E-05	3.58E-05	2.25E-05	1.91E-05	1.78E-05	1.28E-05
Th 230	4.00E-05	3.50E-05	2.40E-05	1.60E-05	1.50E-05	1.40E-05	7.20E-06
Ra 226+	3.42E-05	2.91E-05	1.91E-05	1.20E-05	1.00E-05	9.53E-06	2.23E-06
Pb 210+	1.84E-05	1.83E-05	1.12E-05	7.33E-06	6.01E-06	5.69E-06	1.16E-06
Po 210	1.80E-05	1.40E-05	8.60E-06	5.90E-06	5.10E-06	4.30E-06	2.20E-06
U 235sec	3.95E-04	3.49E-04	2.33E-04	1.62E-04	1.45E-04	1.33E-04	8.30E-05
U 235+	3.00E-05	2.60E-05	1.70E-05	1.10E-05	9.20E-06	8.50E-06	5.70E-06
Pa 231	7.40E-05	6.90E-05	5.20E-05	3.90E-05	3.60E-05	3.40E-05	1.70E-05
Ac 227+	2.91E-04	2.54E-04	1.64E-04	1.12E-04	1.00E-04	9.07E-05	6.03E-05
Th 232sec	2.76E-04	2.38E-04	1.57E-04	1.06E-04	9.25E-05	8.46E-05	4.82E-05
Th 232	5.40E-05	5.00E-05	3.70E-05	2.60E-05	2.50E-05	2.50E-05	1.20E-05
Ra 228+	4.91E-05	4.81E-05	3.20E-05	2.00E-05	1.60E-05	1.60E-05	1.71E-06
Th 228+	1.73E-04	1.40E-04	8.83E-05	5.97E-05	5.15E-05	4.36E-05	3.45E-05
K 40	0	0	0	0	0	0	0

5.4.2. Inhalation of Radon and its decay products

5.4.2.1. General aspects

The calculation of effective doses caused by inhalation of Rn and Rn decay products is based on the models presented in [BMU 99]. The gaseous radionuclides Rn 222 and Rn 220 get into the atmosphere from soil, rock and building materials driven by diffusion processes and from there to the air breathed in by the reference person. The activity concentration of the short-living decay products is calculated using equilibrium factors for the alpha energy concentration of the relevant nuclides.

The modelling of the Rn concentration in air for the scenarios set up here requires a calculation or an empirical assessment of the Rn exhalation rate. Based on this data, the Rn concentration outdoors [BAR 99] respectively indoors [LEH 98] can be calculated

The deposition of industrial residues on landfills or heaps as well as the recycling of NORM as additive material in building materials causes a radon source term which is examined here.

The calculation starts with assumptions for the radon emanation dependant on the material characteristics of the NORM residues. For slags, an emanation fraction of 1% is chosen, for all other types of material considered here, a value of 20% is appropriate. The radon release of a heap or landfill is estimated using the diffusion equation.

The radon concentration on or beside of the heap or landfill is calculated using a generic model, which describes the dispersion of the radon [BS 99]. Concerning buildings, the radon fraction transported into the building from outside (exhalation from sources in the vicinity of the building; e.g. a heap or a landfill) as well as the radon fraction released from contaminated building material are taken into consideration. The ventilation rate in the room as a relevant parameter in estimating the radon concentration in the room is considered here too.

The calculation of Radon concentration in air is performed according to the so called "Berechnungsgrundlagen Bergbau" as described in [BMU 99] and is carried out for Rn 222 as well as for Rn 220 (Thoron). The parameters used for the calculations are described in the following.

5.4.2.2. Estimation of the Rn concentration outside

The Rn exhalation (J) caused by diffusive Rn transport can be calculated according to,

$$J = \rho \cdot R \cdot E \cdot \sqrt{\lambda \cdot D} \cdot \tanh\left(\sqrt{\lambda / D} \cdot H\right), \qquad \text{(eq. 3)}$$

where ρ is the density (dry matter) of the material, R is the specific radium activity (here: identical to the derived exemption/clearance level), E is the emanation coefficient, λ is the decay constant, D the diffusion coefficient and H the height of the emanating object (e.g. a heap or a landfill). This equation is suitable for the estimation of the exhalation rates of Rn 222 by using the values for the specific activity of Ra 226 and for λ the value of $2.1 \cdot 10^{-6}\ s^{-1}$. For the density of the material and the diffusion coefficient the following values are used:

- $\rho = 1.5 \cdot 10^3$ kg/m³; for building material $2.4 \cdot 10^3$ kg/m³
- $D = 2 \cdot 10^{-6}$ m²/s.

Using this value for the diffusion coefficient, the last term in the above equation, tanh(...), turns to a value of nearly 1 for heaps and landfills with a height of H ≥ 2 m.

The emanation coefficient E is dependant on the material characteristics of the NORM residue; also differences with regard to both Rn isotopes have to be taken into consideration. The emanation coefficient describes the fraction of Radon atoms, which gets into the pore volume of the material in the course of the α-decay of Radium and are available for transport. For NORM-material, which was exposed to high temperatures during its production and therefore develops material characteristics of ceramic or glass, the emanation coefficient is in the order of 0.01 (see [LEH 98]). This value is used here with regard to Rn 222 for the material type slag. For the examined material types rock, sand and ash a value of E = 0.2 was used. For rock and sand, this is a typical value with variations of ± 0.1. For ash, this value is rather conservative, especially for fly ash, which was exposed to high temperatures.

The estimation of the emanation coefficient for Rn 220 was derived on the basis of a literature research (for example: [KEL 91], [HOW 95]). As a result, the following relation was derived:

$$E_{Rn\,220} \approx 0.25 \cdot E_{Rn\,222} \,. \qquad \text{(eq. 4)}$$

Concerning the estimation of the mean Rn 222 concentration ($C_{Rn\,222}$) in the atmosphere near the ground on the contaminated area (heap, landfill, place covered with contaminated material, street), [BAR 98] offers a detailed description. The corresponding approximation formula is defined as,

$$C_{Rn\,222} = 11 \cdot Bq/m^3 \cdot J_{222} \cdot \ln(1+1.7 \cdot A), \quad \text{where } J_{222} \text{ is in } Bq/(m^2 \cdot s) \text{ and A in ha,} \qquad \text{(eq. 5)}$$

where A describes the contaminated area. This formula is based on calculations for the dispersion of Rn, which have been validated by a large number of measurements on heaps of the Uranium mining in the former German Democratic Republic.

With regard to the mean Rn 222 concentration ($C_{Rn\,222}$) in the atmosphere beside a contaminated area – e.g. staying outside in a garden or in a building in the vicinity of this area, a detailed description of modelling Rn concentration is presented in [BAR 99].

The following approximation formula is again based on calculation results derived by modelling the dispersion of Rn, which have been validated by numerous measurements of the Rn concentration in the vicinity of heaps resulting from Uranium mining in Germany.

$$C_{Rn\,222} = 377 \cdot Bq/m^3 \cdot Q_{222} \cdot (a/r)^{1.58}, \quad \text{with } Q_{222} \text{ in kBq/s, a and r in m,} \qquad \text{(eq. 6)}$$

where

$$Q_{222} = A \cdot J_{222} \qquad \text{(eq. 7)}$$

represents the Rn 222- emission rate, r the distance from the edge of the contaminated area and a a scaling parameter dependant on geometric characteristics of the exposure situation. This scaling parameter can be determined by aid of the following equations,

$$a = 1.25 \cdot a_{r,A}\,, \qquad \text{(eq. 8)}$$

where the factor 1.25 is a measure for the anisotropy of the meteorological conditions and $a_{r,A}$ is determined according to the following implicit equation,

$$10^3 \cdot A \cdot (a_{r,A} / r)^{1{,}58} \cdot \tan\left(\frac{\pi}{2} \cdot a_{r,A}\right) = 1 \qquad \text{(eq. 9)}$$

with A as the size of the contaminated area (in ha) and r and $a_{r,A}$ in m.

For more details as well as tabular and graphical solutions of equation 9 see [BAR 99], [BMU 98].

5.4.2.3. Estimation of the Rn concentration in buildings

The estimation of Rn concentrations in buildings (houses, ware houses for storage of NORM) requires the determination of the Rn exhalation rate J of the contaminated area A (e.g. walls of the room in a house). When the ventilation rate λ_V of the room with volume V is known, the Rn concentration in the room can be calculated with the following equations (see for example [LEH 98]):

$$C_{Rn} = \frac{J \cdot A}{V \cdot (\lambda_{Rn} + \lambda_V)}. \qquad \text{(eq. 10)}$$

The values for the ventilation rate λ_V as well as for the relation A/V of the exhalating area A referring to the volume V of the room are presented in Table 24:

Table 24: Values for ventilation rate λ_V and for the relationship between the exhaling area A and the volume V of the room

Scenario	**Ventilation rate λ_V in h^{-1}**	**in s^{-1}**	**A/V in m^{-1}**
storage building; scenario 4.2.3a; 4.2.3b	2	$5.56 \cdot 10^{-4}$	A=441 m² V=4000 m³ A/V = 0.11
house (building); scenario 4.2.7; 4.2.8	3	$8.33 \cdot 10^{-4}$	A=44 m² V=30 m³ A/V = 1.467
house (living); scenario 4.3.3; 4.3.4	0.5	$1.39 \cdot 10^{-4}$	A/V = 1.467

Comment on Table 24: The ventilation rate in buildings without technical ventilation equipment (e.g. residences) ranges between 0.5 and 1 h^{-1}. Here the lower value was chosen for the scenario “living in a house near a heap/landfill”. Rooms with ventilation, e.g. storage buildings have a higher ventilation rate due to technical equipment for ventilation. The corresponding values in Table 24 have been chosen with an enveloping character, too (see [EUR 99B], [ANL 93]).

The estimation of Rn exhalation with regard to the scenarios “building a house” and “living in a house” are carried out using the following formula,

$$J = \rho \cdot R \cdot E \cdot \sqrt{\lambda \cdot D} \cdot \tanh\left(\sqrt{\lambda / D} \cdot H_W / 2\right), \qquad \text{(eq. 11)}$$

where H_W is the wall thickness. The factor $H_W/2$ takes into consideration, that the Rn exhalation takes place at both surfaces of the wall. Here, a wall thickness of 0.2 m was chosen.

The formula (eq. 11) describing the Rn exhalation of walls containing NORM material as additive leads to reasonable results, which were verified using measurement results from [MUS 84] for the Rn 222 exhalation of concrete and gypsum. On the basis of (eq. 11) and with regard to the data in [MUS 84], the emanation coefficients and diffusion coefficients relevant for the scenarios analysed here are calculated. The following data for calculation have been derived according to the procedure described above:

- $D_{concrete} = 2 \cdot 10^{-7}$ m²/s with $\rho_{concrete} = 2400$ kg/m³
- $D_{gypsum} = 2 \cdot 10^{-6}$ m²/s with $\rho_{gypsum} = 1500$ kg/m³

5.5. Ingestion dose

5.5.1. Direct ingestion of material

Normally NORM residues and waste will not be ingested, although dust which is deposited on the skin in the course of processing NORM can be inadvertently ingested, for example while smoking a cigarette or eating during a break. An enveloping scenario to describe this exposure might assume that the worker inadvertently incorporates a quantity of 20 g/a (~10 mg/h during 1800 h/a working time) of contaminated material (undiluted) due to dirt on the hands and contact between hands and mouth ([SSK 93], [STU 94], [SSK 98], [IAE 92], [EUR 98]). This quantity is a conservative estimate, as shown in [DEC 94], [EUR 98] and [IAE 92].

Since NORM could also be used for recultivation or ground cover it is conceivable that children could play on these areas and swallow a certain amount of material. Therefore the enveloping scenario for the inadvertent ingestion of building rubble assumes that the ingestion rate for a child (age class 1 to 2 years and 2 to 7 years old) is higher. Details are presented in Table 7.

The resulting ingestion dose is calculated as follows:

$$H_{ing} = D_{ing} \; r_{ing} \; t_{exp} \qquad \text{(eq. 12)}$$

where

H_{ing} [(Sv/a)/(kBq/kg)] individual dose from inadvertent ingestion

D_{ing} [Sv/Bq] dose coefficient (table A Euratom Directive for ages 1 to 2 years old),

r_{ing} [g/h] ingestion rate

t_{exp} [h/a] exposure time per year.

The dose coefficients used for ingestion here are presented in Table 25.

Table 25: Dose coefficients for ingestion used in calculation

Nuclide	<1	1 - 2	2 - 7	7 - 12	12 – 17	> 17	worker
U 238sec	4.64E-05	1.43E-05	7.90E-06	5.83E-06	5.48E-06	2.57E-06	2.57E-06
U nat	7.71E-07	2.84E-07	1.87E-07	1.53E-07	1.49E-07	1.00E-07	1.00E-07
Th 230	4.10E-06	4.10E-07	3.10E-07	2.40E-07	2.20E-07	2.10E-07	2.10E-07
Ra 226+	4.70E-06	9.62E-07	6.21E-07	8.01E-07	1.50E-06	2.80E-07	2.80E-07
Pb 210+	8.42E-06	3.61E-06	2.20E-06	1.90E-06	1.90E-06	6.91E-07	6.91E-07
Po 210	2.60E-05	8.80E-06	4.40E-06	2.60E-06	1.60E-06	1.20E-06	1.20E-06
U 235sec	5.20E-05	5.70E-06	4.00E-06	2.96E-06	2.46E-06	1.97E-06	1.97E-06
U 235+	3.54E-07	1.33E-07	8.62E-08	7.17E-08	7.04E-08	4.73E-08	4.73E-08
Pa 231	1.30E-05	1.30E-06	1.10E-06	9.20E-07	8.00E-07	7.10E-07	7.10E-07
Ac 227+	3.86E-05	4.27E-06	2.81E-06	1.97E-06	1.59E-06	1.21E-06	1.21E-06
Th 232sec	4.12E-05	7.25E-06	4.36E-06	4.62E-06	5.86E-06	1.06E-06	1.06E-06
Th 232	4.60E-06	4.50E-07	3.50E-07	2.90E-07	2.50E-07	2.30E-07	2.30E-07
Ra 228+	3.00E-05	5.70E-06	3.40E-06	3.90E-06	5.30E-06	6.90E-07	6.90E-07
Th 228+	6.55E-06	1.09E-06	6.04E-07	4.31E-07	3.07E-07	1.43E-07	1.43E-07
K 40	0	0	0	0	0	0	0

5.5.2. Calculation of radionuclide content in the groundwater

If the NORM material is disposed of in a landfill or used for backfilling pits etc., it is possible that the activity is washed out of the material and transported with the seepage into a groundwater layer. The groundwater could later be used for various purposes leading to secondary ingestion.

The method for calculating the activity contents in the groundwater and the doses for various uses of the water are described in numerous reports ([DEC 93], [POS 95], [DEC 97], [EUR 95], [IAE 87], [ELE 92], [NEA 89]). The scenario assumes that the entire activity deposited on the heap or landfill site is available for migration and finds its way into the groundwater. Both assumptions must be rated very pessimistic (cf. [DEC 97]).

The procedure described in the following starts from the total amount of radioactivity in the heap and assumes that a certain fraction is released annually with the seepage into the groundwater:

$$A_h = C_{NORM} \cdot m_h \cdot d \qquad \text{(eq. 13)}$$

where

A_h	total activity in the heap [Bq]
C_{NORM}	activity concentration in the NORM material [Bq/g]
m_h	total mass of the heap [g]
d	dilution factor [-]

The fraction which is annually released depends on the NORM material type. The values provided for waste rock in Table 18 are conservative estimates based on actual measurements at heaps in Germany [BAR 99], for the other material types, the release rate is estimated on the basis of material properties in relation to waste rock. The values range from 0.001 to 0.00001 (cf. Table 18).

The annual seepage quantity is calculated as the product of the average annual rainfall per unit area (0.8 m/a), the area of the heap (100,000 m²) and the infiltration (0.25). The activity concentration in the seepage is then simply the total activity times the annually released fraction divided by the seepage quantity:

$$Q_s = a_h \cdot Q_{rain} \cdot r_{inf} \qquad \text{(eq. 14)}$$

$$C_s = A_h \cdot r_{rel} / Q_s \qquad \text{(eq. 15)}$$

where

C_s	activity concentration in the seepage [Bq/m³]
Q_s	annual quantity of seepage [m³/a]
r_{rel}	annually released fraction of the activity in the heap [-]
a_h	area of the heap [m²]
Q_{rain}	annual rainfall [m/a]
r_{inf}	infiltration fraction (of rainfall into the heap) [-]

The next step is to assume a simple mixing of the seepage with the water of a groundwater layer underneath the heap. The annual groundwater flow in this aquifer can be calculated from its depth, the usable pore fraction (0.25), the distance the water travels underneath the heap (square root of the heap area, 316 m), and the groundwater velocity (2 m/d or 730 m/a):

$$Q_{gw} = v_{gw} \cdot h_{gw} \cdot r_{pore} \cdot l_h \qquad \text{(eq. 16)}$$

where

Q_{gw}	annual groundwater flow [m³/a]
v_{gw}	groundwater velocity [m/a]
h_{gw}	height of aquifer [m]
r_{pore}	usable pore fraction [-]
l_h	length of heap [m]

From the values given in Table 18, an annual groundwater flow of $2.9 \cdot 10^5$ m³/a is calculated. It is now assumed that the annual activity travelling with the seepage mixes with this annual groundwater quantity providing the activity concentration in the groundwater.

$$C_{gw} = \frac{C_s \cdot Q_s}{Q_{gw} + Q_s} \qquad \text{(eq. 17)}$$

where

C_{gw}	activity concentration in groundwater [Bq/m³] (the result must be divided by 1000 to obtain the activity concentration in Bq/l)

The resulting activity concentration in groundwater is provided in Table 18 related to 1 Bq/g in the NORM material on the heap. The activity concentrations range from 3.2 Bq/l for material type waste rock down to 0.032 Bq/l.

5.5.3. Calculation of radionuclide content in the crops from irrigation

The following model describing radionuclide transfer to plants is an adaptation from [IAE 94]. It is assumed that the groundwater is used for irrigation of crops (vegetables, fruit etc.) in a private garden. The radionuclides are taken up via the roots and also are deposited on the leaves. The irrigation rate is set to 100 l/(a·m²). All parameter values are presented in Table 17.

The deposition on the leaves can be described as follows: irrigation takes place for 60 d which corresponds to the deposition time over which radionuclides are transferred to the plants. Only a part of the water is retained on the leaves, which can be calculated as the product of the vegetable yield (2 kg/m²), the dry weight fraction of the foliage and an interaction fraction per unit biomass (2 m²/kg) yielding a retention factor of 0.4.

$$C_{crop,dep,j} = \frac{Q_{irr}}{180\,d/a} \cdot \frac{1 - e^{-0.05 \cdot t_{dep}}}{0.05} \cdot f_{ret} \cdot f_{tr} \qquad \text{(eq. 18)}$$

where

$C_{crop,dep,j}$	radionuclide concentration in crops per 1 Bq/g in the water for nuclide j [(Bq/kg)/(Bq/l)]
Q_{irr}	annual quantity of irrigation [l/(a·m²)]
t_{dep}	deposition time (60 d)

f_{ret}	retention factor (0.4; see above)
f_{tr}	translocation factor (0.1)

The root uptake can be described as follows: only 60% of the irrigation reaches the ground. It is assumed that the irrigation is carried out for 25 a. The (normalized) radionuclide concentration in the soil per 1 Bq/l in the water can then be calculated as follows:

$$C_{soil} = \frac{Q_{irr} \cdot f_{gr} \cdot t_{irr}}{d_{root} \cdot \rho_{soil}} \qquad \text{(eq. 19)}$$

where

C_{soil}	radionuclide concentration in the soil per 1 Bq/l in the water [(Bq/kg)/(Bq/l)]
Q_{irr}	annual quantity of irrigation [l/(a·m²)]
f_{gr}	fraction of water reaching ground [-]
t_{irr}	number of years during which irrigation takes place
d_{root}	thickness of root layer [m]
ρ_{soil}	density of soil in the root layer [kg/m³]

From the normalised radionuclide concentration in the soil the concentration in the crops can be calculated by multiplying with the transfer factors for the relevant nuclides.

$$C_{crop,soil,j} = C_{soil} \cdot f_{crop,j} \qquad \text{(eq. 20)}$$

where

$C_{crop,soil,j}$	radionuclide concentration in crops per 1 Bq/l in the water for nuclide j [(Bq/kg)/(Bq/l)]
$f_{crop,j}$	transfer factor to crop for nuclide j

5.5.4. Calculation of radionuclide content in the crops from dust deposition

A further mechanism leading to secondary ingestion is direct deposition of dust on the crops. The deposition velocity is assumed to 0.001 m/s. The deposition time is also 60 d as in section 5.5.3. The retention factor which characterises the fraction of dust incorporated into the plants is set to 0.45. The activity in the plants is then calculated as follows:

$$C_{crop,dust,j} = c_{dust} \cdot f_{dil} \cdot \frac{v_{dep} \cdot 86000\,\mathrm{s/d}}{1000\,\mathrm{g/kg}} \cdot \frac{1 - e^{(-0.05 \cdot t_{dep})}}{0.05} \cdot f_{ret} \cdot f_{tr} \qquad \text{(eq. 21)}$$

where

$C_{crop,dust,j}$	radionuclide concentration in crops for nuclide j [(Bq/kg)]
c_{dust}	dust concentration in the air [g/m³]
v_{dep}	deposition rate (0.001 m/s)
f_{dil}	dilution factor on the heap (mixing with other material) (100%; for sludge: 1%)
t_{dep}	deposition time (60 d)
f_{ret}	retention factor (0.4; see above)
f_{tr}	translocation factor (0.1)

5.5.5. Calculation of doses from secondary ingestion

Age dependent parameter values for the ingestion of fruit and vegetables are provided in Table 7. The dose from ingestion of crops from root uptake is calculated for each age group. It is assumed that only half of the amount of vegetables and fruit is produced in the garden (the rest is bought on the market) and that during washing and cooking half of the activity contents of the crops will be removed. The ingestion dose is then calculated as follows (it must be noted that $C_{crop,dust,j}$ is given in [Bq/kg] while $C_{crop,soil,j}$ and $C_{crop,dep,j}$ are given in [(Bq/kg)/(Bq/l)] and must therefore be multiplied by the radioactivity concentration in the groundwater to obtain the same units):

$$H_{ing,k,j} = (1 - r_{market}) \cdot (Q_{fruit,k} + Q_{veg,k}) \cdot r_{prep} \cdot (C_{crop,soil,j} \cdot C_{gw} + C_{crop,dep,j} \cdot C_{gw} + C_{crop,dust,j}) \cdot D_{ing,k} \quad \text{(eq.22)}$$

where

$H_{ing,k,j}$	ingestion dose from secondary ingestion [Sv/a]
k	index for age group
j	index for nuclide
Q_{fruit}	ingestion quantity of fruit [kg/a]
Q_{veg}	ingestion quantity of vegetables [kg/a]
r_{market}	fraction of fruit and vegetables bought on the market (0.5)
r_{prep}	preparation reduction factor (from cooking/washing of fruit and vegetables) (0.5)

6. RESULTS

6.1. Calculation of exemption / clearance levels

In this section the results of the calculations are presented as activity concentrations (in kBq/kg) for all relevant decay chains and single nuclides concerning NORM and for all five material categories: rock, ash, sand, slag, sludge from oil and gas industry. The notation used for the scenarios refers to the chapter number in which the scenario is described. These are presented in Table 26.

Table 26: Overview of the notation used for the scenarios

Scenario no.	Description of the scenario
Working scenarios	
4.2.1	Transport long distance
4.2.2	Transport short distance
4.2.3a	Storage moderate quantities indoors, with processing
4.2.3b	Storage, moderate quantities indoors, without processing
4.2.4a	Storage, large quantities outdoors, with processing
4.2.4b	Storage, large quantities outdoors, without processing
4.2.5a/b	Disposal/landfill, large/small NORM amount
4.2.6	Road construction
4.2.7	Building construction (concrete walls with NORM additives)
4.2.8	Building construction (gypsum plate walls)
Scenarios for members of the general public	
4.3.1	Playground covered with NORM
4.3.2	Residence near a heap
4.3.3	Building construction (walls of NORM)
4.3.4	Building construction (gypsum plate walls)

The scenarios include all age groups (for working scenarios: only adults, for scenarios with exposure situations for members of the general public: all age groups as defined in the BSS).

The sets of exemption / clearance levels are derived based on the following conditions:

- A dose criterion of 0.3 mSv/a is used as the radiological protection goal concerning the exposure of a reference person (worker or member of the general public) by NORM.
- This dose criterion is to be understood as the extra dose in addition to background. Suitable conservative assumptions on the background dose have been used for each exposure situation. Addition of background dose to the 0.3 mSv/a criterion results in an extended dose criterion (see section 4.1.4) for which the calculations have been carried out. This means that the derived exemption / clearance levels refer to the gross activity of the NORM material.
- As the relevant scenario determining the lowest exemption / clearance level in accordance with the dose criterion described above, the scenario with the highest dose contribution is chosen. This maximum is determined with regard to the ensemble of both categories of reference persons (workers and members of the general public) as well as the maximum of all age groups.
- One set of exemption / clearance levels is determined from the extended dose criterion for each material category examined here (rock, ash, sand, slag, sludge from the oil/gas industry). If appropriate, those sets can be combined.

The following tables show the results of the exemption/clearance level calculations for the five material categories (waste rock: Table 27; ash: Table 28; sand: Table 29; slag: Table 30; sludge from the oil and gas industry: Table 31) in kBq/kg. These tables should be read as follows:

- the heading refers to the scenarios outlined in Table 26; in the corresponding chapter;
- each line lists the results of exemption/clearance level calculations for the nuclide or decay chain for each scenario;
- at the end of each line, the minimum of the scenario specific exemption/clearance levels are given for worker scenarios (4.2.1 – 4.2.8) and for general public scenarios (4.3.1 – 4.3.4);
- the very last column provides the overall minimum;
- columns have been left blank if the specific scenario does not apply to the material type in question.

The exemption / clearance levels are given for all relevant decay chains and single nuclides. The results are shown for each material category and all scenarios examined as well as for all age groups (for working scenarios: only adults, for scenarios with exposure situations for members of the general public: all age groups as defined in the BSS).

Table 27: Results of the calculation of exemption/clearance levels for waste rock type NORM in [kBq/kg]

Scenario	4.2.1	4.2.2	4.2.3a	4.2.3b	4.2.4a	4.2.4b	4.2.5	4.2.6	4.2.7	4.2.8	4.3.1	4.3.2	4.3.3	4.3.4	Min-Work.	Min-Public	Min-All
U-238sec	3.8	2.7	1.3	2.2	1.8	2.6	0.68	0.65	1.2		1.4	0.75	**0.43**		**0.65**	**0.43**	**0.43**
U nat	130	41	**5.2**	18	9.9	37	9.6	12	41		47	28	**33**		**5.2**	**28**	**5.2**
Th 230	280	70	**8.6**	26	16	44	17	22	95		84	27	**5900**		**8.6**	**27**	**8.6**
Ra-226+	4.1	3.5	4.2	4.7	4.5	4.8	0.87	0.78	1.3		2	1.3	**0.44**		**0.78**	**0.44**	**0.44**
Pb-210+	360	90	17	22	20	23	22	29	80		18	**4**	2100		**17**	**4**	**4.0**
Po-210	200	51	9.6	13	11	13	13	16	46		7.5	**3**	91000		**9.6**	**3**	**3.0**
U-235sec	13	5	**0.73**	2.1	1.3	3.5	1	1.2	3.2		3.1	1.8	1.7		**0.73**	**1.7**	**0.73**
U-235+	120	61	10	27	17	41	7.4	8.3	18		18	18	**6.5**		**7.4**	**6.5**	**6.5**
Pa-231	91	26	**3.4**	9.4	6	14	6	7.6	26		25	7.2	33		**3.4**	**7.2**	**3.4**
Ac-227+	18	6.9	**1**	3.1	1.8	5.2	1.4	1.7	4.7		4.5	2.6	2.4		**1**	**2.4**	**1.0**
Th-232sec	2.5	1.9	0.96	1.9	1.4	2.4	0.49	0.45	0.86		1.2	0.56	**0.3**		**0.45**	**0.3**	**0.3**
Th-232	180	45	5.4	18	10	32	11	14	65		52	**3.1**	10000		**5.4**	**3.1**	**3.1**
Ra-228+	7.7	6.3	6	6.8	6.5	7	1.5	1.4	2.4		2.8	1	**0.82**		**1.4**	**0.82**	**0.82**
Th-228+	3.8	2.9	1.4	3.1	2.3	4.1	0.78	0.7	1.4		2.2	1.4	**0.47**		**0.7**	**0.47**	**0.47**
K-40	41	36	58	58	58	58	9.9	8.3	14		24	18	**4.2**		**8.3**	**4.2**	**4.2**

Table 28: Results of the calculation of exemption/clearance levels for ash type NORM in [kBq/kg]

Scenario	4.2.1	4.2.2	4.2.3a	4.2.3b	4.2.4a	4.2.4b	4.2.5	4.2.6	4.2.7	4.2.8	4.3.1	4.3.2	4.3.3	4.3.4	Min-Work.	Min-Public	Min-All
U-238sec	3.8	2.7	1.3	1.8	1.8	2.2	**0.68**	4.7	3.4	2.3	12	1.2	1	1.5	**0.68**	**1**	**0.68**
U nat	130	41	**5.2**	9.9	9.9	18	9.6	85	120	18	430	29	79	82	**5.2**	**29**	**5.2**
Th-230	280	70	**8.6**	16	16	26	17	160	270	26	760	44	14000	7200	**8.6**	**44**	**8.6**
Ra-226+	4.1	3.5	4.2	4.5	4.5	4.7	**0.87**	5.7	3.8	5.2	18	1.6	1.1	1.5	**0.87**	**1.1**	**0.87**
Pb-210+	360	90	**17**	20	20	22	22	210	220	22	160	24	5100	1400	**17**	**24**	**17**
Po-210	200	51	**9.6**	11	11	13	13	120	130	13	68	14	2.2E5	3.0E5	**9.6**	**14**	**9.6**
U-235sec	13	5	**0.73**	1.3	1.3	2.1	1	8.7	9.1	2.1	28	2.6	4	4.2	**0.73**	**2.6**	**0.73**
U-235+	120	61	10	17	17	27	**7.4**	61	49	25	160	18	16	15	**7.4**	**15**	**7.4**
Pa-231	91	26	**3.4**	6	6	9.4	6	55	74	9.5	230	15	79	84	**3.4**	**15**	**3.4**
Ac-227+	18	6.9	**1**	1.8	1.8	3.1	1.4	12	13	3	40	3.8	5.8	6.2	**1**	**3.8**	**1.0**
Th-232sec	2.5	1.9	0.96	1.4	1.4	1.9	**0.49**	3.3	2.4	2.1	11	0.87	0.72	1.1	**0.49**	**0.72**	**0.49**
Th-232	180	45	**5.4**	10	10	18	11	100	180	18	480	16	25000	12000	**5.4**	**16**	**5.4**
Ra-228+	7.7	6.3	6	6.5	6.5	6.8	**1.5**	10	6.8	7.1	25	2.5	2	2.8	**1.5**	**2**	**1.5**
Th-228+	3.8	2.9	1.4	2.3	2.3	3.1	**0.78**	5.1	3.8	3.6	20	1.4	1.1	1.8	**0.78**	**1.1**	**0.78**
K-40	41	36	58	58	58	58	**9.9**	60	40	68	220	18	10	18	**9.9**	**10**	**9.9**

Table 29: Results of the calculation of exemption/clearance levels for sand type NORM in [kBq/kg]

Scenario	4.2.1	4.2.2	4.2.3a	4.2.3b	4.2.4a	4.2.4b	4.2.5	4.2.6	4.2.7	4.2.8	4.3.1	4.3.2	4.3.3	4.3.4	Min-Work.	Min-Public	Min-All
U-238sec	3.8	2.7	1.3	1.8	1.8	2.2	0.68	0.76	1.2		1.4	1.3	**0.43**		**0.68**	**0.43**	**0.43**
U nat	130	41	**5.2**	9.9	9.9	18	9.6	14	41		47	30	33		**5.2**	**30**	**5.2**
Th-230	280	70	**8.6**	16	16	26	17	26	95		84	50	5900		**8.6**	**50**	**8.6**
Ra-226+	4.1	3.5	4.2	4.5	4.5	4.7	0.87	0.92	1.3		2	1.6	**0.44**		**0.87**	**0.44**	**0.44**
Pb-210+	360	90	**17**	20	20	22	22	33	80		18	37	2100		**17**	**18**	**17**
Po-210	200	51	9.6	11	11	13	13	19	46		**7.5**	22	91000		**9.6**	**7.5**	**7.5**
U-235sec	13	5	**0.73**	1.3	1.3	2.1	1	1.4	3.2		3.1	2.9	1.7		**0.73**	**1.7**	**0.73**
U-235+	120	61	10	17	17	27	7.4	9.8	18		18	18	**6.5**		**7.4**	**6.5**	**6.5**
Pa-231	91	26	**3.4**	6	6	9.4	6	8.9	26		25	18	33		**3.4**	**18**	**3.4**
Ac-227+	18	6.9	**1**	1.8	1.8	3.1	1.4	2	4.7		4.5	4.2	2.4		**1**	**2.4**	**1.0**
Th-232sec	2.5	1.9	0.96	1.4	1.4	1.9	0.49	0.53	0.86		1.2	0.93	**0.3**		**0.49**	**0.3**	**0.3**
Th-232	180	45	**5.4**	10	10	18	11	17	65		52	28	10000		**5.4**	**28**	**5.4**
Ra-228+	7.7	6.3	6	6.5	6.5	6.8	1.5	1.7	2.4		2.8	2.8	**0.82**		**1.5**	**0.82**	**0.82**
Th-228+	3.8	2.9	1.4	2.3	2.3	3.1	0.78	0.82	1.4		2.2	1.4	**0.47**		**0.78**	**0.47**	**0.47**
K-40	41	36	58	58	58	58	9.9	9.7	14		24	18	**4.2**		**9.7**	**4.2**	**4.2**

Table 30: Results of the calculation of exemption/clearance levels for slag type NORM in [kBq/kg]

Scenario	4.2.1	4.2.2	4.2.3a	4.2.3b	4.2.4a	4.2.4b	4.2.5	4.2.6	4.2.7	4.2.8	4.3.1	4.3.2	4.3.3	4.3.4	Min-Work.	Min-Public	Min-All
U-238sec	3.8	2.7	1.3	2.2	1.8	2.6	0.68	0.65	1.2		1.4	1.3	**0.43**		**0.49**	**0.43**	**0.43**
U nat	130	41	**5.2**	18	9.9	37	9.6	12	41		47	49	33		**5.2**	**33**	**5.2**
Th-230	280	70	**8.6**	26	16	44	17	22	95		84	87	5900		**8.6**	**84**	**8.6**
Ra-226+	4.1	3.5	4.2	4.7	4.5	4.8	0.87	0.78	1.3		2	1.6	**0.44**		**0.58**	**0.44**	**0.44**
Pb-210+	360	90	**17**	22	20	23	22	29	80		18	27	2100		**17**	**18**	**17**
Po-210	200	51	9.6	13	11	13	13	16	46		**7.5**	15	91000		**9.6**	**7.5**	**7.5**
U-235sec	13	5	**0.73**	2.1	1.3	3.5	1	1.2	3.2		3.1	3.6	1.7		**0.73**	**1.7**	**0.73**
U-235+	120	61	10	27	17	41	7.4	8.3	18		18	21	**6.5**		**7.3**	**6.5**	**6.5**
Pa-231	91	26	**3.4**	9.4	6	14	6	7.6	26		25	25	33		**3.4**	**25**	**3.4**
Ac-227+	18	6.9	**1**	3.1	1.8	5.2	1.4	1.7	4.7		4.5	5.2	2.4		**1**	**2.4**	**1.0**
Th-232sec	2.5	1.9	0.96	1.9	1.4	2.4	0.49	0.45	0.86		1.2	0.93	**0.3**		**0.35**	**0.3**	**0.3**
Th-232	180	45	**5.4**	18	10	32	11	14	65		52	22	10000		**5.4**	**22**	**5.4**
Ra-228+	7.7	6.3	6	6.8	6.5	7	1.5	1.4	2.4		2.8	2.6	**0.82**		**1**	**0.82**	**0.82**
Th-228+	3.8	2.9	1.4	3.1	2.3	4.1	0.78	0.7	1.4		2.2	1.5	**0.47**		**0.56**	**0.47**	**0.47**
K-40	41	36	58	58	58	58	9.9	8.3	14		24	18	**4.2**		**6.6**	**4.2**	**4.2**

Table 31: Results of the calculation of exemption/clearance levels for sludge type NORM (oil and gas industry) in [kBq/kg]

Scenario	4.2.1	4.2.2	4.2.3a	4.2.3b	4.2.4	4.2.5	4.2.6	4.2.7	4.2.8	4.3.1	4.3.2	4.3.3	4.3.4	Min-Work.	Min-Public	Min-All
U-238sec	55	47	**5.6**	7		60					70			**5.6**	**70**	**5.6**
U nat	5900	5100	**85**	490		860					1900			**85**	**1900**	**85**
Th-230	4.0E6	3.4E6	**150**	58000		1500					2000			**150**	**2000**	**150**
Ra-226+	55	48	**7**	7.1		77					130			**7**	**130**	**7**
Pb-210+	6.9E13	6E13	**200**	32000		2000					390			**200**	**390**	**200**
Po-210	1.2E7	1.0E7	**110**	1.5E6		1100					290			**110**	**290**	**110**
U-235sec	390	330	**9.2**	27		90					140			**9.2**	**140**	**9.2**
U-235+	2400	2000	**69**	100		660					1600			**69**	**1600**	**69**
Pa-231	7100	6200	**54**	530		540					590			**54**	**590**	**54**
Ac-227+	490	430	**13**	39		130					220			**13**	**220**	**13**
Th-232sec	36	31	**4.9**	4.7		44					53			**3.9**	**53**	**3.9**
Th-232	2.3E7	2.0E7	**100**	150000		1000					290			**100**	**290**	**100**
Ra-228+	110	91	**12**	13		140					100			**12**	**100**	**12**
Th-228+	54	47	**6.1**	7.2		69					130			**6.1**	**130**	**6.1**
K-40	550	480	**78**	**78**		860					1700			**78**	**1700**	**78**

In Figure 2 the final results of the five material type are summarised.

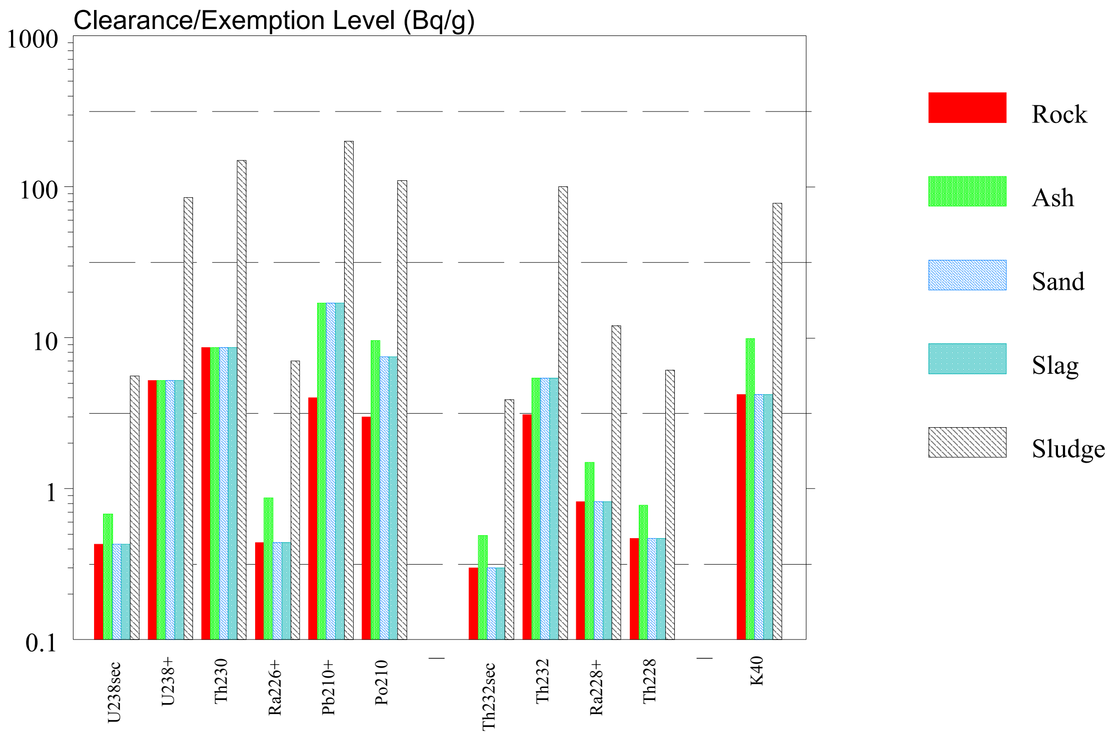


Figure 2: Comparison of final results of the clearance/exemption level calculations (based on all ages and all pathways) - values taken from the last columns of Table 27 to Table 31.

This figure clearly shows that for the types waste rock, ash, sand and slag the differences are minimal. For these materials one single set of exemption / clearance values could be derived. For sludges from the oil and gas industry, however, the calculated values are higher by about one order of magnitude. Those exemption / clearance values should therefore be treated separately.

The dose calculations carried out in this document do not include the following pathways:

- inhalation of radon and its decay products,
- ingestion of contaminated groundwater from a well (drinking water).

These two pathways are discussed separately in sections 6.2 and 6.3 below.

6.2. Inhalation of radon/radon decay products and ingestion via groundwater pathway

Concerning the estimations on radon concentrations with regard to the scenarios examined here, the procedure was chosen as follows:

- The calculation of the Rn 222 concentration in air is based on the minimum value of all exemption/clearance levels for Ra 226+ for each type of material. The exhalation rate J was calculated according to the formulae described in section 5.4.2.
- Based on the results for the exhalation rate J, the radon concentration $C_{Rn\ 222}$ was derived as described in section 5.4.2.

The results for the calculation of radon concentrations with regard to the scenarios examined here are presented in Table 32.

Table 32: Exhalation rate J and concentration of Rn 222 for the various scenarios

Scenario	Description of exp. situation and relevant parameters	Exhalation rate J [Bq/m²s]	Rn222 concentr. C_{Rn222} [Bq/m³]	Remarks
Exposure scenarios concerning workers				
4.2.1	Transport-long distances; radon exposure fully covered by scenario 4.2.3			
4.2.2	Transport-short distances; radon exposure fully covered by scenario 4.2.3			
4.2.3	storage moderate quantities, indoors, heap with H=3 m, ρ=1500 kg/m³, A=441 m², V=4000 m³; A/V=0.11, λ_V=2/h	Rock: 0.246 Ash: 0.307 Sand: 0.246 Slag: 0.012	Rock: 57,3 Ash: 71.6 Sand: 57,3 Slag: 2.8	calc. of J accord. to eq. 3 calc. of C_{Rn222} accord. to eq. 10
4.2.4	storage large quantities, outdoors, heap with H=6 m, ρ=1500 kg/m³, A=0.21 ha (2.1·10^3 m²), distance heap 10m	Rock: 0.246 Ash: 0.307 Sand: 0.246 Slag: 0.012	Rock: 1.7 Ash: 2.15 Sand: 1.7 Slag: 0.08	calc. of J accord. to eq. 3 calc. of C_{Rn222} accord. to eq. 6
4.2.5	disposal on a heap, H=10 m, ρ=1500 kg/m³, A=10 ha (10^5 m²) for "rock", 1 ha for other types of material	Rock: 0.246 Ash: 0.307 Sand: 0.246 Slag: 0.012	Rock: 7.82 Ash: 3.35 Sand: 2.68 Slag: 0.13	calc. of J accord. to eq. 3 calc. of C_{Rn222} accord. to eq. 5
4.2.6	road construction; radon exposure fully covered by scenario 4.2.5			
4.2.7	building construction with NORM containing material; room: A=44 m², V=30 m³, A/V=1.467, λ_V=3/h	Rock: 30 Ash: 25 Sand: 30 Slag: 10	Rock: 14.6 Ash: 12.2 Sand: 14.6 Slag: 4.9	calc. of J accord. to eq. 11 calc. of C_{Rn222} accord. to eq. 10
4.2.8	building construction using undiluted NORM as unshielded surface cover; radon exposure fully covered by scenario 4.2.7			
Exposure scenarios concerning members of the general public				

Scenario	Description of exp. situation and relevant parameters	Exhalation rate J [Bq/m²s]	Rn222 concentr. C_{Rn222} [Bq/m³]	Remarks
4.3.1	NORM additives in building material for public places, radon exposure fully covered by scenario 4.2.5			
4.3.2	person living in a house near a heap/landfill with H=10 m, ρ=1500 kg/m³, A=10 ha (10^5 m²) for "rock", 1 ha for other types of material, "rock": a=0,1875 for distance to garden (r=20 m) other material: a=0,4375 for distance to garden (r=20m) "rock": a=0,2 for distance to house (r=25 m) other material: a=0,5 for distance to house (r=25m)	*on the heap:* Rock: 0.246 Ash: 0.307 Sand: 0.246 Slag: 0.012 *in the garden:* Rock: 0.246 Ash: 0.307 Sand: 0.246 Slag: 0.012 *in the house:* Rock: 0.246 Ash: 0.307 Sand: 0.246 Slag: 0.012	*on the heap:* Rock: 7.82 Ash: 3.35 Sand: 2.68 Slag: 0.13 *in the garden:* Rock: 5.8 Ash: 2.76 Sand: 2.2 Slag: 0.11 *in the house:* Rock: 4.51 Ash: 2.39 Sand: 1.92 Slag: 0.09	calc. of J accord. to eq. 3, calc. of C_{Rn222} accord. to eq. 5 (heap), eq. 6 (garden, house)
4.3.3	person living in a house built with NORM containing material, A=44 m², V=30 m³, A/V=1.467, λ_V=0.5/h	Rock: 30 Ash: 25 Sand: 30 Slag: 10	Rock: 86.6 Ash: 72.2 Sand: 86.6 Slag: 28.9	calc. of J accord. to eq. 11 calc. of C_{Rn222} accord. to eq. 10
4.3.4	person living in a house made of undiluted NORM as unshielded surface cover; radon exposure fully covered by scenario 4.3.3			

The results show that the radon level of 200 Bq/m³ is not exceeded for any exposure scenario concerning members of the general public as considered here. The same applies to the worker scenarios for which the results have to be compared with a level of 500 Bq/m³. Therefore, the exemption/clearance levels as derived here are compatible with the radiation protection goals concerning radon exposure.

6.3. Drinking water ingestion via the groundwater pathway

The groundwater pathway is relevant with regard to the scenario 4.3.2 ("Residence near a heap"). In this case it is assumed that the water is used for irrigation of plants in a private garden. The ingestion dose is calculated according to section 5.5. The following radionuclide concentrations have been calculated (referring to 1 kBq/kg Uranium in the releasing material):

- for rock material: 3.2 Bq/l
- for ash material: 0.32 Bq/l
- for sand material: 0.032 Bq/l
- for slag material: 0.32 Bq/l
- for sludges from the oil and gas industry: 0.032 Bq/l

If the groundwater was used as drinking water, considerably higher doses could occur than from irrigation. However, guidelines exist that limit the content of Uranium in drinking water:

- The WHO guideline contain a provisional level of 2 µg/l uranium in drinking water. This limit would be exceeded here.

- Another possibility of evaluating the concentration of uranium in the well water with regard to allowable concentrations as defined in already existing guidelines is the comparison with the drinking water guideline of the EU, which definies a dose criterion of 0.1 mSv/a by ingestion of the contaminated water. The following estimations show that the resulting doses calculated according to the scenarios examined here, are higher than 0.1 mSv/a:

  - According to the NORM exemption/clearance level of 0.4 kBq/kg for U 238sec derived here (Table 27 to Table 30), the following radionuclide contents in the well water would occur: 1.3 Bq/l for material type “rock” and 0.13 Bq/l for the material types “ash” and “slag”.

  - Assuming only consumption of water as drinking water (as in RP 113: 500 l/a for adults, 200 l/a for children (1-2 a)) and using the dose factors $2.6 \cdot 10^{-6}$ Sv/Bq for adults resp. $1.4 \cdot 10^{-5}$ Sv/Bq for children the following doses due to drinking contaminated well water are derived:

    - ♦ adults: 1.7 mSv/a (rock) and 0.17 mSv/a (ash/slag)

    - ♦ children (1-2 a): 3.6 mSv/a (rock) and 0.36 mSv/a (ash/slag)

This evaluation shows that in cases where the use of groundwater as drinking water could not be precluded a case by case evaluation of possible doses is necessary.

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Sources, Effects and Risks of Ionizing Radiation; 1988 Report to the General Assembly, with annexes; United Nations, New York, 1988

Abstract

The provisions on work activities involving exposures to natural radiation sources are given in Title VII of the 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 from ionising radiation. Regarding exemption and clearance, Article 5.2 and 3.2 are the relevant parts of Title III referred to in Article 41.b.

The present document deals with the concepts of exemption and clearance in the frame of natural radiation sources and industries processing NORM (naturally occurring radioactive materials). Guidance of the Group of Experts established under Article 31 of the Euratom Treaty is provided, including characterisation of the types of NORM residues considered, generic enveloping exposure scenarios, exposure pathways and parameter values used to calculate clearance levels for natural radionuclides.

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