Untersuchungen zu aktuellen Fragestellungen zur Sicherheit bei der Beförderung radioaktiver Stoffe

Abschlussbericht zum Forschungsvorhaben CRP NORM der IAEO im Rahmen des Vorhabens 3607R02600 (AP 3)

Exposure of Transport Workers from the Transport of Most Important NORM in Germany

GRS - A - 3541

Gesellschaft für Anlagen-
und Reaktorsicherheit
(GRS) mbH

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Anmerkung:

Das diesem Bericht zu Grunde liegende FE-Vorhaben 3607R02600 wurde im Auftrag des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit durchgeführt. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt beim Auftragnehmer.

Der Bericht gibt die Auffassung und Meinung des Auftragnehmers wieder und muss nicht mit der Meinung des Auftraggebers übereinstimmen.

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Abstract

The German national report to the IAEA co-ordinated research project (CRP) “The appropriate level of regulatory control for the safe transport of naturally occurring radioactive material (NORM)” was focused on the following services according to the research agreement:

- Status review, analysis and evaluation of the radiation exposure imposed by shipment and exposure due to the shipment staff of most relevant NORM in Germany;
- Development of evaluation criteria and safety requirements to provide adequate safety standards for the transportation of NORM, and
- Development and application of procedures to determine the limits for exempt materials/consignments for transportation according to German Transport Regulations for all NORM.

For the analysis and evaluation of the radiation exposure due to the shipment of NORM for ten different materials a couple of transport scenarios were defined and the dose to transport workers was calculated.

For the calculation of the dose to transport personnel measured data of radionuclide concentrations in these materials were used. The model parameters were taken from authorized dose calculation procedures related to remediation of legacies from uranium mining and milling and adapted to the relevant transport scenarios or determined by experiments.

The defined transport scenarios included both, the drivers of transport vehicles as well as the staff dealing of loading and unloading. Furthermore, it was divided between scenarios for bulky or unpackaged transport and packaged transport. It could be demonstrated that only for bulky transport scenarios the dose due to inhalation of contaminated dust has to be considered in addition to the external dose by γ-radiation.

Special attention was paid on the dose resulting from transport of materials with non-equilibrium of radionuclides of the Uranium-Radium-decay chain and the Thorium-decay chain. That concerns e.g. pipe scales and drilling sludge from oil and gas exploitation.

The most relevant results are:

- The given 10fold limit for exempt materials according to TS-R-1, e.g. 100 Bq g^{-1} for Radium isotopes, is only a theoretical limit because in case of non-equilibrium the transportation limit for exemption is derived from the formula given in para. 405;
- As the value of activity concentration for exempt material of Thorium isotopes is by a factor of 10 lower than the value of Radium isotopes, the limit of activity concentration decisively depends on the share of Th 228 (f_{Th228}) in nuclides mixture when applying this formula;
- The external dose by γ–radiation depends solely from the activity concentration of Ra 226 and/or Ra 228 independent on the equilibrium status within these decay chains;
- Subsequently, for all scenarios for transport of packaged materials where only the external dose must be considered, the Radium activity concentration is linear correlated to the dose independent of the kind and the indented use of the material.

Finally, on the basis of the dose calculation results for the transport of NORM recommendations are given as far as the proposed dose limit of 0.3 mSv yr^{-1} for transport personnel is accepted.

Contents

1 Introduction

In the Federal Republic of Germany there are – as reported by recent statistics – about 650.000 up to 750.000 consignments of radioactive substances annually routed (apart from consumer goods) in domestic and trans-boundary transportation via road, rail, air and waterways. Regarding their kind, amount and properties, these radioactive substances are various materials and goods for scientific, medical, industrial and nuclear applications like radioactive medications, radiation sources, test irradiators, residues and waste, emptied packages containing residue activity, nuclear fuel etc., but also residues from non-nuclear fields of application with elevated contents of natural radionuclides (NORM). The major part of these consignments ranges between small and medium activity values from some MBq up to some GBq, which are routed from the site of their manufacturing or storage to the site of their application or employment; whereas larger or very big activity values makes only a fractional amount of the German total transportation amount.

From the view of transportation law, radioactive substances are hazardous goods, which can put public safety and order at risk, if unduly handled or in case of accidents. Therefore, the protection and safety during shipment of radioactive substances should be optimized as to keep the individual doses values, the number of persons exposed to radiation and the likelihood of radiation exposure which regard to economic and social factors „as low as reasonably achievable“ (ALARA).

Having introduced and applied safety requirements of transportation directives of 1996 in national binding law, the safety requirements have been made more stringent inter alia by the introduction of new, more restrictive nuclide specific activity limits for exempt material or consignment for diverse materials containing such radionuclides. There, as the recent experience shows, this counts especially for smaller additives of natural radionuclides into materials like construction materials, industrial products, minerals (e. g. zirconium sands, tantalite), mineral fertilizers, etc. These materials which are generally denominated as NORM (Naturally Occurring Radioactive Material), due to their special properties belong since then to the application area of stringent safety requirements of the international transportation directives.

In the recent years, the commensurability of the classification and categorization of that kind of low-active materials and hazardous goods has been disputed by various parties. Therefore, to scrutinize pertaining transportation safety and radiation protection aspects, the International Atomic Energy Agency (IAEA) has initiated a Co-ordinated Research Programme (CRP) on the „Safety of Transport of Naturally Occurring Radioactive Material“ with participation of its member states. The objective of CRP is to check the commensurability of judgement criteria for classification and categorization of materials, containing smaller amounts of natural radioactivity and, if appropriate, to develop modified safety requirements and criteria for their shipment.

Under this CRP, the GRS delivered the following services:

- Overall status review and categorization of most important low-active materials and durable goods containing natural radionuclides in Germany;
- Status review, analysis and evaluation of NORM shipments and expected radiation exposure of the shipment staff and the population for chosen NORM materials, durable goods and transportation areas taking into account the usual shipment manner and package forms;
- Development and checks of evaluation criteria and safety requirements to provide adequate safety standards for the transportation of NORM;
- Procedures to determine the limits for exempt materials/consignments for transportation according to ADR for NORM in non-equilibrium, the applicability of homogeneity criteria according to the recommendation of the IAEA and relevance of associated conventional harmful substances.

This report on hand contains calculations of exposure of transport workers from the transport of most important NORM in Germany.

2 Methodical Approach

The principal legal basis for the status review of the most relevant materials and consumer goods with elevated contents of natural radionuclides is the German Radiation Protection Ordinance, especially § 3 No. 18 with definitions of consumer goods, to which other radioactive substances belong as stipulated in § 2 sec. 1 of the German Atomic Law (AtG) /ATG 09/ - in this case exclusively natural radionuclides – as well as

§ 97 with Annex XII, Part A on supervised residues or other materials according § 102 of the Radiation Protection Ordinance (StrlSchV) /SSV 08/.

The shipment of radioactive substances is ruled by Section 4 of the StrlSchV with § 16 on licensed shipment and § 17 on non-licensed shipment as well as § 18 licensing conditions for shipment and §§ 19 through 22 on trans-boundary disposal or transportation. Especially regarding consumer goods, §§ 108 and 109 rule their trans-boundary disposal. Also Annex A of ADR /ADR 09/ is relevant for transportation of NORM, especially No. 1.7.1.4 e), according to which substances and ores containing only natural radionuclides shall only be attributed to Class 7 of ADR if they exceed 10fold-value of that stipulated in No. 2.2.7.2.2.1 or of the calculated value according to No. 2.2.7.2.2.2 to No. 2.2.7.2.2.6 (especially No. 2.2.7.2.2.4).

Also TENORM are covered by the most recent amendment of Annex A of the ADR for application of the 10-fold activity limiting value according to No. 1.7.1.1 e) ADR /ADR 09/. For this, the IAEA (TRANSSC VII) made a definite clarification, according to which the identical to IAEA Safety Standard Series No. TS-R-1 /IAE 09/ (translated) text in Nr. 1.7.1.4 e) ADR with Documents UN/SCETDG/20/INF 29 and ST/SG/AC.10/C.3/2002/55 of 13.05.2002 by the UN was taken over to harmonize the recommendations of the IAEA.

For actual NORM substances, there is a very complex perception, which is to be put down to the introduction of a „Positive Indication List“ as Annex XII Part A of the StrlSchV. There, only residues with elevated contents of natural radionuclides had been decisive for amendments to the StrlSchV as relevant mining and industrial sectors to be listed as in Table 2.1. Table 2.1 contains also raw materials which apply to the definition of NORM. All other NORM substances are other materials according to § 102 StrlSchV, of which the substances listed in Table 3.1 can be relevant for the project.

Table 2.1 List of residues to be taken into account according to Annex XII, Part A of StrlSchV /SSV 08/ as well as their origin and relevant raw materials

No.	Industrial process	Raw material	Residue or product
1	Natural gas and crude oil exploitation	Drilling mud, connate water	mud and scales
2	Wet processing	Phosphogipsum	mud
	Acidic pulping	Raw phosphate (Phosphori-te)	unprocessed phosphogipsum
	Thermal processing	Raw phosphate (Phosphori-te)	dust, slag
3a	Mining and milling	Bauxite, Columbite, Pyro-chlor, Microlyth, Euxenite, Copper-, Tinn-, Rare Earth- and Uranium ore	Surrounding rock, mud, sand, slag and dust
	Processing	Concentrates or residues of ores and minerals basing upon No. 3a	Surrounding rock, mud, sand, slag and dust
3b	Extraction and proces-sing	Other raw materials	Minerals corres-ponding to above men-tioned ores
4	Flue gas cleaning on primary smelting	Iron ores, non iron ores	dust and mud

For the following materials listed in Table 2.1 transport scenarios were defined and the dose to transport workers was calculated.

- Tantalum raw materials (Microlyte, Tantalite, Columbite, Tin slag)
- Raw phosphate
- Pipe scales and drilling sludge from oil and gas exploitation
- Coal ash
- Waste rock material from Uranium mining
- Zircon raw materials (Pegmatite, Baddeleyite)
- Titanium dioxide raw materials (Ilmenite, Rutile)
- Filter gravel from water works

3 Application of the transport regulations to NORM

3.1 Conditions for exemption

Under the StrlSchV there is initially no limitation for specific activity for release of residues from the supervision under § 98 No. 1 of the StrlSchV which is bound to keeping at the dose limits of 1 mSv/a per capita of the population – also for occupationally exposed staff of the landfill. However, limitations imposed by specific activity for decisions on release of NORM residues from the radiological supervision or keeping them under the provision of the Radiation Protection Ordinance do not stem from Chapter 3 of the StrlSchV but from regulations of the Transportation Law, especially those for hazardous goods shipment under the ADR /ADR 09/ and RID /RID 08/ Class 7. That results from the acceptance conditions for underground dumpsite (dumpsite Class DK IV) and some other landfills for special waste (dumpsite Class DK III) /DVO 09/, which, according to the dumpsite approval procedure may not accept residues delivered under Class 7 of the ADR.

For all residues elucidated in this Chapter, the 10fold clearance values are effective as established in Table 2.2.7.2.2.1 of the ADR for sole nuclides or which result from the sum formula according to values given in 2.2.7.2.2.4 of the ADR. Regulation 107(e) (IAEA TS-R-1) /IAE 09/ states:

“The Regulations do not apply to:

Natural material and ores containing naturally occurring radionuclides that are either in their natural state, or have been processed only for the purposes other than for the extraction of the radionuclides, and that are not intended to be processed for the use of these radionuclides, provided that the activity concentration of the material does not exceed 10 times the values specified in Table 2 or calculated in accordance with paras 403 - 407”.

Paragraph 402 of TS-R-1 refers to Table 2 with exempt activity concentrations in Bq g^{-1} for each radionuclide. In case of non-equilibrium which is true for most TENORM the limit for exempt material is derived from the formula of Annex 1 of the ADR (para. 2.2.7.2.2.4) (or para. 405 in /IAE 09/):

$$X_m = 1 / \sum_i f(i) / Xi \qquad \textbf{(1)}$$

where

f(i) share of the activity concentration of radionuclide i in mixtures and

X(i) exempt value of the activity concentration for nuclide i.

As the value of activity concentration for exempt material from the ADR (Table 2.2.7.2.2.1) e. g. for Th 228-activity concentration is by factor 10 lower than this for both Ra-isotopes, Pb 210 and Po 210, the limit of activity concentration decisively depends on the share of Th 228 (f_{Th228}) in nuclides mixture, the actual activity concentration for exempt material ranging between the extrema 10 Bq g^{-1} (containing only Th 228) and 100 Bq g^{-1} (no Th 228 contained). As formula (1) demonstrates, this value does not change linearly with the Th-228 share. Therefore, this results in „variable limit of activity concentration for exempt material“, as demonstrated in Figure 1. This leads to serious problems both during the process of release of residues from supervision according to § 98 of the StrlSchV as well as concerning the exemption of the transportation under the ADR Class 7.

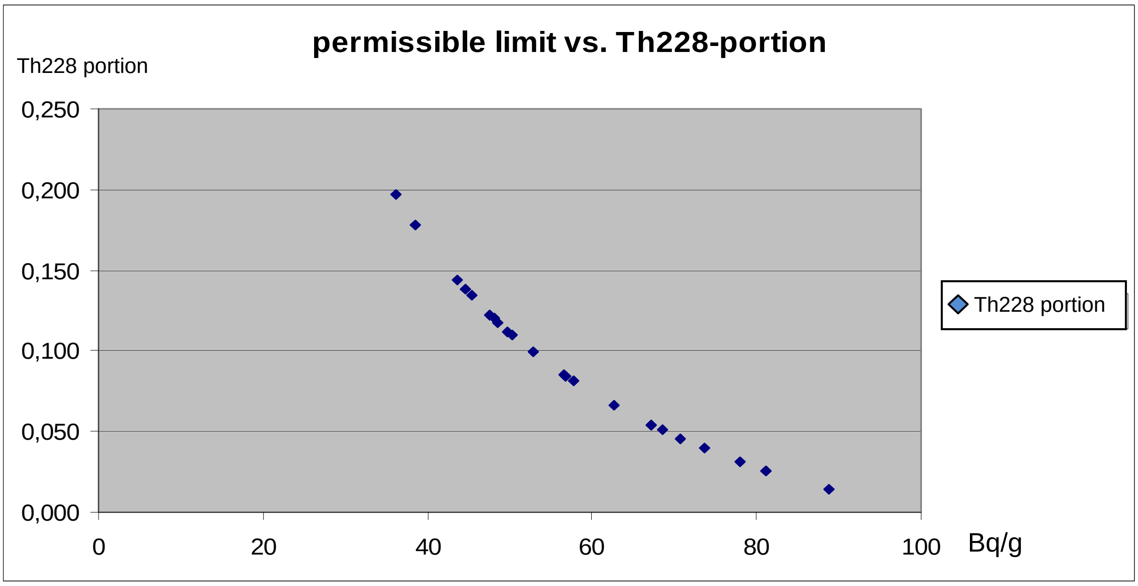

Figure 1 Limit of activity concentration for exempt material in dependence on the Th 228 fraction in scales from German natural gas fields

Furthermore, the question comes up which radionuclides of the Uranium-Radium-chain and the Thorium-chain must be used in formula (1) for the calculation of the exempt value in case of non-equilibrium. For all long lived radionuclides of the mentioned decay chains Table 2 of TS-R-1 refers to footnote (b), where these parent nuclides and their progenies included in secular equilibrium are listed. That gives the reason for the only use of these „mother nuclides“ listed in Table 2. This approach would also agree with the procedure applied for the definition of activity concentrations for the release of NORM from radiological supervision. The dose conversion factors which are applied for the calculation of limits of radionuclide concentrations (only long lived) include already the short lived daughter nuclides.

3.2 Homogeneity criterion

In addition, the question should be answered if for clearance of a consignment with contaminated scrap (e. g. pipe + scales from oil and gas industries) the specific activity of scales or the mass-weighted activity from pipe + scales is effective. On this matter, there are different opinions. While some German federal states accept the notification on "pipe + scales", some other federal states take solely the specific activity (or activity per unit surface) of scales as the basis for exemption, the latter with reference to para. 240 or para. 241 of the IAEA transport regulations /IAE 09/.

The contrary interpretations are based on the following assumptions:

a) Scale and pipe material are no homogeneous object

Rationale: "Scales and pipe are regarded as non-homogeneous, as scales can peel away from pipes during transportation and both components are then no unity."

In Germany this position is based primarily on the directive of the ADR, which stipulates that for determination of the class of the mixture (e. g. the pipe and scales are regarded as a mixture), the most hazardous component is decisive while the share of this component being irrelevant. Another argument is that a (partial) peel-away of scales from the pipe wall by mechanical load during transportation, e. g. by accident, cannot be ruled out. Regarding radiological consequences of e. g. a transportation vehicle fire (as most severe assumed accident), the radioactivity release and therefore resulting radiation exposure is independent from the distribution of radioactivity within the contaminated scrap in the container.

b) Scales and pipe material are a homogeneous object

Rationale: “Scales and pipe are a homogeneous object due to the strong fixation of the scales at the inner wall of pipes. Even if scales peel away from pipes during transportation they remain in the container which will be stored in the underground storage without reopening.”

In IAEA No. TS-R-1 /IAE 09/, providing the basis for the ADR Class 7, the “homogeneity criterion” serves in the first instance to give evidence of keeping below the activity limiting value and to determine the total activity of the consignment. Here, the specific activity values measured in determined parts or segments (samples) may not significantly differ. Therefore, such sample can be a part of pipe with scales, for there are contaminated pipes and no separate scales that will be transported, whereas later separation to recycle the bearer material (pipes) is not intended.

This reasoning is employed inter alia by competent regulatory bodies in Saxony and Brandenburg, which however require sealing of open endings of pipes (e. g. by protective caps). The sealing of the pipes by protective caps is already required for transportation of contaminated pipes from oil and gas industry within a single enterprise, which is primarily due to the presence of mercury (partly in metallic form). This means that the homogeneity criterion is met and therefore the specific activity of transportation goods results from mass-weighted activity of the pipe + precipitation (scales).

The following Table 3.1 provide the actual status of ADR-relevant share of such NORM residues for which transport scenarios are described and evaluated.

Table 3.1 Activity concentration for exempt material according to ADR /ADR 09/ for selected NORM

No.*	Branch / Process	Material	Reference nuclide	Exempt value (FG) [Bq g^{-1}]	Amount for ADR transport [t yr^{-1}]	Remarks
1	Crude oil exploitation	Mud	^{228}Ra	20 – 28 (36)[1,2] 7.6 – 6.7 (5.8)[3]	~ 150	FG depends on $^{228}Ra/^{226}Ra$-ratio of the deposit; data from /KOL 85/
		separated scales	^{228}Ra	20 – 28 (36)[1,2] 7.6 – 6.7 (5.8)[3]	~ 20	
		Scrap	^{228}Ra	100 – 140 (180)[1,2] 38.0 – 33.5 (29.0)[3]	~ 1,000	Specific activity in scales for a mass related ratio “tube/scale” = 5
2	Natural gas exploitation	Mud	^{226}Ra	27 – 40 (67) [1,2] 6.1 – 17.6 (30.2)[3]	~ 100	FG depends on $^{228}Ra/^{226}Ra$-ratio of the deposit; data from /KOL 85/, /WEI 03/
		separated scales	^{226}Ra	27 – 40 (67) [1,2] 6.1 – 17.6 (30.2)[3]	~ 30	
		Scrap	^{226}Ra	135 – 200 (335) 30.5 – 88.0 (150)	~ 3,000	Specific activity in scales for a mass related ratio “tube/scale” = 5
3a	Uranium mining	Waste rock material	^{238}U	10		Huge amounts from remediation of former Uranium mining and milling sites
3a	Niobium / Tantalum manufacture	Tinn slag	$^{238}U + ^{232}Th$	10	75,000 – 85,000	
		Microlyte	$^{238}U + ^{232}Th$	10		
		Tantalite	$^{238}U + ^{232}Th$	10		
		Columbite	$^{238}U + ^{232}Th$	10		
-	Zirconium industry	Pegmatite, Baddeleyite	$^{238}U + ^{232}Th$	10	~ 15,000	Milled raw material for further processing

No.*	Branch / Process	Material	Reference nuclide	Exempt value (FG) [Bq g^{-1}]	Amount for ADR transport [t yr^{-1}]	Remarks
-	Titanium dioxide pigment industry	Ilmenite	^{238}U + ^{232}Th	10	420,000	Total quantity of Titanium containing raw materials importet to Germany per year
		Rutile	^{238}U + ^{232}Th	10		
-	Coal combustion	Fly ash	^{238}U + ^{232}Th or ^{210}Pb	10 15 – 25	no	The activity of fly ash related to Ra 226 is less than 0.2 Bq g^{-1} and rules out from provision of radiation protection ordinance
		Bottom ash	^{238}U + ^{232}Th	10	no	The activity of fly ash related to Ra 226 is less than 0.2 Bq g^{-1} and rules out from provision of radiation protection ordinance
-	Waterworks	Filter gravel	^{226}Ra	20 – 60 6 - 28	?	sporadically; depending on portion of ^{228}Ra

* according to Annex XII part A of StrlSchV /SSV 08/

1 in brackets exempt values (FG) for scales from deposits where the $^{228}Ra/^{226}Ra$-ratio is < 0,1
2 FG = 1 / [C_{Ra226}/(100 x AS) + 2x C_{Pb210}/(100 x AS) + C_{Ra228}/(100 x AS) + 1,2 x C_{Ra228}/(10x AS)]; (1,2 x C_{Ra228} = C_{Th228})
3 maximum specific activity of reference nuclide related to the particular FG
4 dry matter

3.3 The radioactive equilibrium within the natural decay chains

A radioactive steady state is considered for the residues of group A1 and A2 (see Table 3.2). These heaped-up materials are of mining origin or resulting from mechanical ore processing.

The residues resulting from chemical processes (group B) are characterized by non-equilibrium conditions reflecting the chemical property of each chemical element, i.e. it is equal for all isotopes of one and the same element. These NORM and TENORM are either the result of natural chemical processes as for scales by co-precipitation of radium isotopes with barium to barium-radium-sulphate (baryte) or of technological processes as phosphor-gypsum from acidic treatment of raw phosphate.

The nuclide relations in residues of group C result from the volatility of each element, i.e. with enrichment of the isotopes of the high volatile elements lead and polonium in dust or fly ash.

The following Table 3.2 contains an overview on the different equilibrium and non-equilibrium relations of NORM wastes as result of the technological process of their appearance. While for the air path and the path of direct ingestion the actual nuclide relationship within the natural decay chains will be applied, for the water path the temporal changes of the nuclide relations must be taken into account when considering a long observation period of some hundred years.

Table 3.2 Nuclide relations for different NORM and TENORM

Group	Nuclide relations
A1 A2	U 238sec → same specific activity of all nuclides of U-Ra decay chain For U 235 decay chain: U 235 : U 238 = 1 : 20 Th 232sec → same specific activity of all nuclides of Th decay chain
B1	Sulfate scales: Ra 226+ → same specific activity of Ra 226,Rn 222 and short lived RnDP; „regrowing of Pb/Po210 Ra 228+ → same specific activity of Ra 228 and Ac 228; „regrowing“ of Th 228 by “dynamic equilibrium” Lead scales: Pb 210++ → same specific activity of Pb 210, Bi 210 and Po 210 Carbonate-, silicate- and fluoride scales: like sulphate scales
B2	1. Ra 226+ → same specific activity of Ra 226, Rn 222 and short lived RnDP; „regrowing“ of Pb/Po210 Ra 228+ → same specific activity of Ra 228 and Ac 228; „regrowing“ of Th 228 by „dynamic equilibrium“ 2. Acidic leaching of phosphate: Ra 226++ → same specific activity from Ra 226 to Po-210 U 238+ → same specific activity of U 238 and U 234 with initially 20 % of Ra 226 activity 3. red mud: U 238sec → same specific activity of all nuclides of U-Ra decay chain
B3 (WTS)	Depending on the applied separation method U238+ and/or Ra226+ and/or Ra226++, and/or Pb210++
C1	Pb210++ → same specific activity of Pb210, Bi210 and Po210; for fly ash: U238++ →initially 20 % of Pb210
C2	U 238++ → same specific activity from U 238 to Ra 226; „regrowing“ of Pb/Po210 Th 232sec → same specific activity of all nuclides of Th decay chain

4 Calculation basis for specific transportation scenarios

4.1 Parameters for the calculation of external exposure

According to /SSK 06/ the following parameters could by applied to specific transport scenarios:

$f_{Kon,j}$: Conversion factor from equivalent dose in effective dose for the reference person „employee“: 0.6

g_{ext}: Conversion factor for the calculation of the out-door equivalent dose in the height of 1.0 m by means of activity concentrations of the soils in Sv kg Bq^{-1} h^{-1}.

This is effective for:

Uranium-Radium decay chain in radioactive equilibrium or for Ra 226+ in non-equilibrium:

$$g_{ext} = 5.3 \cdot 10^{-10} \text{ Sv kg Bq}^{-1} \text{ h}^{-1}$$

The comparable conversion factor within the Thorium decay chain in radioactive equilibrium or for Th 228+ in non-equilibrium is:

$$g_{ext} = 8.0 \cdot 10^{-10} \text{ Sv kg Bq}^{-1} \text{ h}^{-1}$$

Nevertheless, these ratios are only applicable for large surface areas of one or more acres (e.g. waste rock piles). Measurements of gamma dose at contaminated materials of much smaller extension, e.g. on gravel filter beds from water works lead to

$$g_{ext} = 2.0 \cdot 10^{-10} \text{ Sv kg Bq}^{-1} \text{ h}^{-1}$$

for the Uranium-Radium decay chain in radioactive equilibrium or for Ra 226+ in non-equilibrium and of

$$g_{ext} = 3.0 \cdot 10^{-10} \text{ Sv kg Bq}^{-1} \text{ h}^{-1}$$

for the Thorium decay chain in radioactive equilibrium or for Th 228+ in non-equilibrium.

Furthermore, it is proposed to apply:

Shielding factor μ of steel (ρ = 7.5 g cm^{-3}): μ = 0.47 cm^{-1} (for 1 MeV)

4.2 Parameters for calculation of internal exposure by inhalation of dust

$\dot{V}_j$: breathing rate for the reference person „employee": 1.2 $m^3 h^{-1}$

S_{Staub}: technical reference value of dust concentration: $5 \cdot 10^{-7}$ kg m^{-3}

effective for loading and unloading of bulk material.

for all other transportation scenarios, effective is S_{Staub} : $1 \cdot 10^{-7}$ kg m^{-3}

The following Table 4.1 compiles the inhalation dose coefficients[1)] $g_{Inh,r,j}$ for the radionuclide r as well as inhalation dose coefficients $g_{Inh,j}$ of the radionuclide mixture [2)] for the reference person "employee".

Table 4.1 Inhalation dose coefficients $g_{Inh,r,j}$ for radionuclide r and $g_{Inh,j}$ for the radionuclide mixture for the reference person "employee", respectively

Radionuclide	$g_{Inh,r,j}$ [Sv Bq^{-1}] und $g_{Inh,j}$ [Sv Bq^{-1}] [1]
Uran-Radium-chain	
U 238	1.6 E-06
U 234	2.1 E-06
Th 230	7.2 E-06
Ra 226	2.2 E-06
Pb 210	1.1 E-06
Po 210	2.2 E-06
U-Ra chain (steady state)	1.6 E-05
Thorium-chain	
Th 232	1.2 E-05
Ra 228	1.7 E-06
Th 228	3.2 E-05
Th chain (steady state)	4.6 E-05
Mixture [2)]	5.0 E-05

[1] Guideline 96/29/Euratom of the Council of 13.May 1996

1) Dose coefficients are effective for pulmonary absorption class M (for Th class S) pursuant to ICRP Publication 71 (para. 58). For Ac pulmonary absorption class F is effective.

2) Dose coefficients for the mixture take into consideration only the Uranium-Radium- and the Uranium-Actinium-decay chain and were calculated assuming a natural activity correlation of both decay chains in radioactive equilibrium of 20:1 as :

$$g_{Inh,j} = g_{Inh,U\text{-}238,j} + g_{Inh,U\text{-}234,j} + g_{Inh,Th\text{-}230,j} + g_{Inh,Ra\text{-}226,j} + g_{Inh,Pb\text{-}210,j} + g_{Inh,Po\text{-}210,j} + \quad \textbf{(2)}$$

$$+ 0{,}05 \cdot (g_{Inh,U\text{-}235,j} + g_{Inh,Pa\text{-}231,j} + g_{Inh,Ac\text{-}227,j})$$

4.3 Parameters for calculation of internal exposure by inhalation of Rn 222 and its short lived daughter products

Calculation of radiation exposure on the basis of values of Radon 222-concentration.

$$H_{Rn,j} = g_{EEC,j} \sum_{s} \left(C_{Rn,s} - C^{U}_{Rn,s}\right) t_{Exp,j,s} F_{Rn,s} \quad \textbf{(3)}$$

$H_{Rn,j}$ = Effective annual dose by inhalation of Radon-222 and ist short-lived decay products for a reference person j in Sv

$g_{EEC,j}$ = Conversion dose coefficient of a reference person j for the product [1] from Radon-222 exposure and equilibrium factor $F_{Rn,s}$ in Sv m^3 Bq^{-1} h^{-1}, where $g_{EEC,j}$ = 7.8 E-09 Sv m^3 Bq^{-1} h^{-1} /SSK 09/

$C_{Rn,s}$ = mean annual Radon-222 concentration for the exposure site s in Bq m^{-3}

$C^{U}_{Rn,s}$ = Radon-222 concentration of a natural ground for the exposure site s in Bq m^{-3}

$F_{Rn,s}$ = factor to describe the radioactive equilibrium between Rn 222 and its short-lived decay products, where $F_{Rn,s}$ = 0.4 /SSK 09/

$t_{Exp,j,s}$ = annual time of stay of the reference person j at the exposure location s in h

To calculate the Radon concentration in storage rooms, the following simplified equation approach, so called „Leningrad-Formula“ is employed:

$$C_{Rn}\,[Bq\ m^{-3}] = Rn_{Exh}\,[Bq\ m^{-2}\ s^{-1}] \times A\,[m^2] \times (1/\ LWZ)\,[s]\ /\ V\,[m^3] \quad \textbf{(4)}$$

[1] This product is also designated as equilibrium equivalent concentration - EEC

with

C_{Rn} = Radon 222 concentration

Rn_{Exh} = Radon Exhalation rate

A = Surface

LWZ = Ventilation number

V = Volume of the storage room

To calculate the Radon concentration above out-door storage ground, approximation formula pursuant to /SSK 09/ is employed:

$$C_{Rn,i} = 11\ J_i \ln\left(1 + 1{,}7F_i\right) \tag{5}$$

which herein means:

$C_{Rn,i}$ = mean Radon-222 concentration for an outdoor storage or facility i in Bq m^{-3}

J_i = Radon-222 exhalation rate for an outdoor storage or facility i in Bq m^{-2} s^{-1}

F_i = surface of for the outdoor storage or facility i in ha

This approximation equation is employed also for exposure locations directly at the border of the stored materials.

To define Radon release from the residues pursuant to Annex XII Section A of the StrlSchV, the following models and assumptions were used:

The Radon exhalation rate is also defined as in /BAR 99/ on the basis of the diffusion model pursuant to /DIX 84/.

$$J_{Rn} = E_{Rn}\ \lambda_{Rn}\ C_{Ra}\ \rho\ L_D \tanh\ (L_M/L_D) \tag{6}$$

with

J_{Rn} = Exhalation rate of Rn 222 or Rn 220 in Bq m-^{2} s^{-1}

E_{Rn} = Emanation share of Rn 222 or Rn 220 (dimensionless)

λ_{Rn} = Decay constant von Rn 222 oder Rn 220 in s^{-1}

C_{Ra} = Specific activity of Ra 226 or Ra 228 in Bq g^{-1}

ρ = Density of material in g m^{-3}

L_M = Thickness of material in m

L_D = Diffusion length in m

The diffusion length L_D is defined as

$$L_D = \sqrt{D_{Rn} / \lambda_{Rn}} \quad \textbf{(7)}$$

with

D_{Rn} = Radon diffusion coefficient of material in $m^2\, s^{-1}$

The Radon concentration, arising from radon releases from residues in a room (storage or underground landfill chamber) can be calculated on the basis of the following approximating equation /DIX 84/:

$$C_{Rn} = J_{Rn}\, A_M / V_R\, (\lambda_{Rn} + \lambda_R) \quad \textbf{(8)}$$

where

C_{Rn} = Concentration of Rn 222 or Rn 220 in the room air in Bq m^{-3}

A_M = Surface of the source in m^2

V_R = Room volume in m^3

λ_R = Air exchange rate in s^{-1}

There, simple geometric ratios between the surface of the source and the room volume must be introduced (A_M / V_R) /EUR 99/.

- **Exhalation from a semispheric pile**

The surface is $2 \times \Pi \times R^2$. The radius R is $(1.5 \times V / P)^{1/3}$, which corresponds to the thickness L_M in (6). From this follows that:

$$A_M / V_R = 2\, \Pi\, L^2 / V_R \quad \textbf{(9)}$$

- **Exhalation from drums**

This corresponds to the layout of vertical pipe with the upward opening. If the height of the drum is L, then the surface of the upper opening is V_O / L, whereas V_O is the volume of the source (drum). Therefore, the ratio of the surface to the room volume is:

$$A_M / V_R = V_O / V_R\, L \quad \textbf{(10)}$$

- **Exhalation from a thin material layer**

This concerns the deposition of scales on the inner surface of extraction pipes for crude oil and gas. Assuming a thin layer of a uniform distribution, the surface of the contaminated material is roughly the same as that of the pipe's inner surface, which pursuant to /EUR 99/ is $6\ V_R^{\ 2/3}$. Therefore:

$$A_M / V_R = 6\ V_R^{\ -1/3} \qquad \textbf{(11)}$$

For practical reasons, in order to determine the exhalation, it is proposed to calculate the surface of a **pile of pipes** as follows:

$$A_M = \Pi\ d_I\ L\ n \qquad \textbf{(12)}$$

where

d_I = inner diameter of a pipe (if applicable incl. scales) in m

L = length of pipes in m

n = number of pipes

5 Description of scenarios and material-specific parameters used for dose calculation

5.1 Tantalum raw material: Bulk cargo from railcar yard to plant on road

Scenario description:

1. Loading of the truck with tantalum raw materials from storage silo at railcar yard
2. Transport of bulk material from yard to plant on road

Table 5.1 Specific activities in raw materials used for manufacture of Niobium and Tantalum

Material*	**Specific activity [Bq g^{-1}]**		**Source**	**Remarks**
	U_{nat}	Th_{nat}		
Microlyte	15 – 140 120 (max.)	 11	/WEI 05/ /GEL 03/	
Tantalite	1 - 14 14 (max.) 5 - 12 16.4 (68.1)	 3.9 5 - 80 1.3 (11.1)	/WEI 05/ /GEL 03/ /POF 02/ /CHA 07/	 78 % of tantalite shipments > 10 Bq/g (U+Th)
Columbite	15 – 30 30 (max.) 5 - 12	 10 (max.) 5 - 80	/WEI 05/ /GRS 02/ /POF 02/	70 % share on total importet amount of tantalum raw materials
Tin slag	20 (max.) 1.1 18.8 (92.2)	7 (max.) 0.3 6.5 (27.8)	/GEL 03/ /GRS 02/ /CHA 07/	Import: > 10,000 t/yr 45 % of slag ship-ments > 10 Bq/g (U+Th)
Tin melting slag	0.07 – 5.4	0.07 – 15.0	/GRS 02/	
* total quantity of imported tantalum raw materials: 75,000 – 85,000 t/yr				

Table 5.2 Values of specific activities used for dose calculation

Material	**Specific activity [Bq g^{-1}]**	
	U_{nat}	Th_{nat}
Microlyte	30	10
Raw material*	7.5	2.5
* 10fold exempt limit for Tantalum raw materials with the ratio of 3 to 1 between both decay chains		

Table 5.3 Parameters and assumptions applied for dose calculation

Topic	Yard worker	Truck driver
External exposure		
Hours per journey / loading	6 hours per day for loading of tucks	6 journeys per day
Journeys per year	-	60
Hours worked per year	500	600 (incl. 250 hr return journey without freight)
Shielding (steel), cm		0.5
Distance from load, m		1.0 (250 hr)
Distance from silo, m	1.0	3.0 (100 hr)
Dust inhalation		
Dust concentration, mg m^{-3}	0.5	0.5* / 0.05
Hours worked per year in area with enhanced dust concentration	500	100
Concentration factor (dust fraction $\leq$ 0.02 mm)	2.0	
Radon-222 inhalation		
Emanation rate	0.2	
Density of material, g cm^{-3}	2.5	
Radon diffusion coefficient, m^2 s^{-1}	2.0 E-06	
Deposit thickness, m	2.0 (storage silo)	
Area of silo, m^2	100	
Hours worked per year in area with enhanced Rn 222 activity	500	100
* it is assumed that the truck driver stays close to the storage silo where the dust concentration is enhanced		

Table 5.4 Ratio of γ-dose rate at distance x (m) vs. γ-dose rate at surface of the storage silo

Distance [m]	Value
0.5	0.65
1.0	0.45
3.0	0.15

For the relation between the specific activity of Ra 226 or Ra 228 and the γ-dose rate at the surface of the silo the ratio calculated for drum surface was used as follows:

1 Bq g^{-1} Ra 226 ~ 0.2 μSv h^{-1}
1 Bq g^{-1} Ra 228 ~ 0.3 μSv h^{-1}

5.2 Phosphate: Bulk cargo from ship to plant on road

Scenario description:

1. Debarkation of raw phosphate by means of belt loader and interim storage at storage area
2. Loading of trucks with raw phosphate by means of Front-End Loader from storage silo at railcar yard
3. Transport of bulk material from storage area to plant

Table 5.5 Specific activities in raw materials used for manufacture of phosphate fertilizers

Material*	Specific activity [Bq g^{-1}]		Source	Remarks
	U_{nat}	Th_{nat}		
Raw phosphate	1.7	0.03	/GRS 02/	Phosphorite, Morocco
	0.39	0.025	/GRS 02/	Phosphorite, Russia
	1.2	-	/FAT 08/	Phosphorite, Jordan
	1.5 – 1.7	< 0.2	/POF 02/	Phosphorite, Morocco
	0.06	0.09	/NRI 02/	Kola apatite
	1.2	-	/ICP 02/	Phosphorite, Brazil
	1.0	-	/ICP 02/	Phosphorite, Israel
* total quantity of imported raw phosphate: 100,000 t/yr (Israel) and 50,000 t/yr (other countries)				

Table 5.6 Values of specific activities used for dose calculation

Material	Specific activity [Bq g^{-1}]	
	U_{nat}	Th_{nat}
Raw phosphate	1.5	0.1

Table 5.7 Parameters and assumptions applied for dose calculation

Topic	Front-end loader driver	Truck driver	Belt loader operator
External exposure			
Hours per journey / loading	6 hours per day for truck loading	6 hours per day	8 hours per day
Journeys per year		60	25
Hours worked per year	500	600 (incl. 250 hr empty trip)	200
Shielding (steel), cm	1.5	0.5	
Distance from bulk shipment, m		1.0 (250 hr)	1.0
Distance from storage area, m	1.0	5.0 (100 hr)	
Dust inhalation			
Dust concentration, mg m^{-3}	0.5	0.5* / 0.05	0.5
Hours worked per year in area with enhanced dust concentration	500	100	200
Concentration factor (dust fraction $\leq$ 0.02 mm)	1.0		
Radon-222 inhalation			
Emanation rate	0.2		
Density of material, g cm^{-3}	2.0		
Radon diffusion coefficient, $m^2\ s^{-1}$	2.0 E-06		
Deposit thickness, m	3.0		
Area of deposit, m^2	500		
Hours worked per year in area with enhanced Rn 222 activity	500	100	200

* it is assumed that the truck driver stays close to the storage area where the dust concentration is enhanced

The conversion factor g_{ext} (ratio between the specific activity of Ra 226 or Ra 228 to the γ-dose rate at 1 m height; see Chapter 4.1) was used.

5.3 Pipe scale: Shipment of tubes in small freight container from scrap yard to underground repository on road

Scenario description:

1. Manual loading of freight containers with tubes at interim storage area
2. Loading of low-loading truck by fork lift truck
3. Transport of freight containers from storage area to repository
4. Unloading of freight containers at above ground warehouse by fork lift truck

The mean specific activity (Ra 226 + Ra 228) of scales + pipe is in most cases less then 10 Bq g^{-1} according to /GEL 03/.

For the calculation of the gamma-dose rate at different distances from the container surface /WEI 03/ evaluates measurements of γ-dose rate which were carried out at containers with contaminated pipe scrap for different distances. Figure 2 shows values from all measurements with curves normalised at D_0 = 10,000 nSv hr^{-1} as compared to the calculated values.

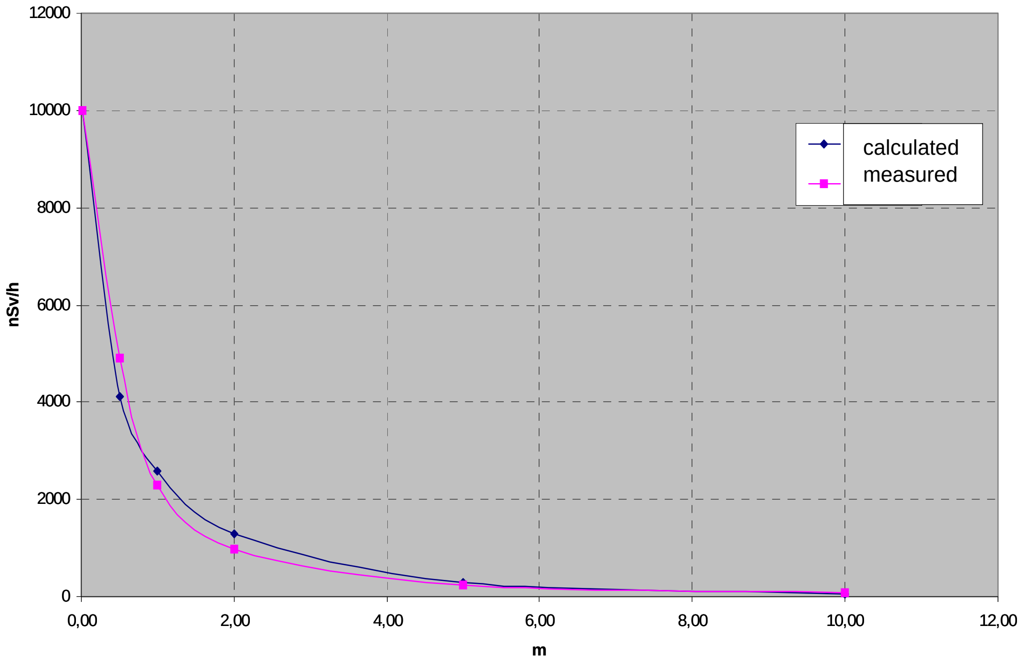

Figure 2 Comparison between the curves from the measurements (normalised) and those calculated in /WEI 03/.

The initial data to calculate the curves (ratio values) as well as for this distance recommended ratio value between γ-dose rate (γ-DR) at a respective distance and the γ-DR at the container's surface are shown in Table 5.8. The variability of ratio values between γ-DR at the container surface as compared to that of γ-DR for smaller distances (0.50 m and 1.00 m) results, on the one hand, from the inhomogeneity of γ-DR at the surface and, on the other hand, from in field experiments unavoidable deviations of the distance of the detectors from the container towards the pre-determined distance.

Table 5.8 Median ratio values of γ-dose rate (ambient dose rate) on the surface of the container to γ-DR in defined distance to the container (less background)

Distance [m]	**Relation value of DR in dist. x [m] : DR at container surface**				
	Mean	**S.D.**	**Minimum**	**Maximum**	**recommended**
0.50	0.4903	0.0704	0.4199	0.5607	0.55
1.00	0.2293	0.0420	0.1297	0.3282	**0.30**
2.00	0.0966	0.0201	0.0568	0.1306	0.15
5.00	0.0240	0.0057	0.0147	0.0458	0.05
10.00	0.0068	0.0015	0.0038	0.0104	0.01

For a practical application, e. g. to calculate external radiation exposure it is proposed to use respectively rounded off maxima of the distance-dependent DR ratio values (s. Table 5.8, column 6 "recommended"). Usage of (rounded-off) maxima, makes sure that these values can also be applied for a pile of containers pile with changed and, regarding the areal propagation of the DR, more adverse geometry.

Table 5.9 Parameters and assumptions applied for dose calculation

Topic	Fork-lift truck driver	Truck driver	Warehouseman
External exposure			
Hours per journey / loading	0.5 hr d^{-1} for truck loading	8 hr d^{-1} (4 hr with load)	6 hr d^{-1} for loading of 6 containers
Journeys per year	25x loading	25	25x loading
Hours worked per year	12.5	200 (incl. 100 hr empty trip)	150
Shielding (steel), cm		1.0	
Distance from tubes, m			0.0 (50 hr)/0.5 (50 hr)
Distance from container, m	1.0 (12.5 hr)	1.5 (100 hr)	0.0 (25 hr)/0.5 (25 hr)
Dust inhalation: No process-related dust emergence due to caps on pipes			
Radon-222 inhalation			
No measurable Radon release due to small exhalation rate of scales of 0.005 Bq m^{-2} s^{-1}			

The ratio between specific activity of Ra 226 and Ra 228, resp. in scales at the inner wall of tubes and γ-dose rate at container surface is:

10 Bq g^{-1} Ra 226 (scales in tubes) ~ 190 nSv hr^{-1} (container surface).

10 Bq g^{-1} Ra 228 (scales in tubes) ~ 300 nSv hr^{-1} (container surface).

The ratio between specific activity of Ra 226 and Ra 228, resp. in scales at the inner wall of tubes and γ-dose rate at tube surface is:

10 Bq g^{-1} Ra 226 (thickness: 1.0 mm; density 4.0 g cm^{-3}) ~ 65 nSv hr^{-1}.

10 Bq g^{-1} Ra 228 (thickness: 1.0 mm; density 4.0 g cm^{-3}) ~ 100 nSv hr^{-1}.

Both values are only valid for the nuclide vector describe in the GRS report prepared for 2nd RCM (Chapter 5.3) /WEI 08/.

5.4 Pipe scale: Shipment of unpackaged pipes from drilling platform to pipe rack on road

Scenario description:

1. Loading of low-loading truck by crane
2. Transport of pipes from drilling platform to pipe rack
3. Unloading of pipes at pipe rack with fork lift truck

The mean specific activity (Ra 226 + Ra 228) of scales + pipe is in most cases less then 10 Bq g^{-1} according to /GEL 03/.

Table 5.10 Parameters and assumptions applied for dose calculation

Topic	Fork-lift truck driver	Truck driver	Crane operator	Floorman
External exposure				
Hours per journey / loading	1.0	2.0; 1 hr with load	0.5	0.5
Journeys per year	20	20	20	20
Hours worked per year	20	40; 20 with load	10	10
Shielding (steel), cm		1.0		
Distance from a pack of tubes, m	1.0	1.5 (20 hr)	3.0	
Distance from single tube, m				0.5
Dust inhalation				
No process-related dust emergence due to caps on pipes				
Radon-222 inhalation				
No measurable Radon release due to small exhalation rate of scales of 0.005 Bq m^{-2} s^{-1}				

The ratio between specific activity of Ra 226 in scales at the inner wall of tubes to γ-dose rate at tube surface is:

10 Bq g^{-1} Ra 226 (thickness: 1.0 mm; density 4.0 g cm^{-3}) ~ 65 nSv hr^{-1} (see Chapter 5.3).

5.5 Pipe scale: Shipment of scales in drums or big bags from storage area to processing plant on road

Scenario description:

1. Transport of drums from warehouse to truck and loading of truck by fork lift truck
2. Transport of drums from storage area to processing plant

Table 5.11 Specific activities in pipe scales

Material	Specific activity [Bq g^{-1}]				Source
	Ra 226	Pb 210	Ra 228	Th 228	
Crude oil scales	300 (max.)	230 (max.)	390 (max.)	500 (max.)	/GRS 02/
Natural gas scales	1,000 (max.) 520	320 (max.) 110	360 (max.) 150	480 (max.) 175	/GRS 02/ /WEI 01/
Oil & gas scales	75 – 150 690 (max.)		25 -50 230 (max)		/GEL 03/

The total amount of scales (dry) is about 20 – 60 t yr^{-1} according to /WEI 05/.

The Ra 228 : Ra 226 activity ratio varries according to /KOL 85/ as follows:

Natural gas scales: 0.57 (0.01 – 1.68)
Crude oil scales: 1.78 (0.40 – 4.43)

Despite the big variability of the Ra 228 : Ra 226 activity ratio for all German on-shore fields this ratio is nearly constant for each single oil or gas field independent on the activity level of scales.

Table 5.12 Recommended values of specific activities used for dose calculation

Material	Specific activity [Bq g^{-1}]			
	Ra 226	**Pb 210***	**Ra 228**	**Th 228**
Natural gas scales, "Gommern field"	100	55	40	50
Calculated exempt limit (40 Bq g^{-1}) using nuclide vector from Gommern gas field	13.2	7.4	5.2	6.8
* Po 210 in equilibrium				

Table 5.13 Ratio of γ-dose rate at distance x (m) vs. γ-dose rate at surface of a pile of drums /WEI 03/ or big bags /FAT 08/

Distance [m]	Recommended value	
	drums	**Big bags**
0.5	0.50	0.65
1.0	0.25	0.50
2.0	0.12	0.30
5.0	0.04	

Table 5.14 Parameters and assumptions applied for dose calculation

Topic	Fork-lift truck driver	Truck driver	Warehouseman
External exposure			
Hours per journey / loading	2 hr d^{-1} for truck loading	8 per day (4 with load)	2 hr for loading of drums
Journeys per year	20x loading	20	20x loading
Hours worked per year	40	160; 80 with load	40
Shielding (steel), cm		0.5	
Distance from drums, m	1.0 (40 hr)		0.0 (20 hr)/0.5 (20 hr)
Distance from load, m		1.0 (80 hr)	
Dust inhalation			
No process-related dust emergence due to caps on pipes			
Radon-222 inhalation			
Exhalation rate, Bq m^{-2} s^{-1}	0.005		
Density of material, g cm^{-3}	4.0		
Radon diffusion coefficient, m^2 s^{-1}	1.0 E-17		
Deposit thickness, m	0.8 (height of a drum)		
Drum surface (100 drums of 0.2 m^2 each), m^2	20		
Hours worked per year at area with enhanced Rn 222 activity	20*	0	40

* Hours worked in-door (warehouse)

The ratio between specific activity of Ra 226 in scales in drums (200 l) and γ-dose rate at drum surface is:

10 Bq g^{-1} Ra 226 ~ 2 μSv hr^{-1} at drum surface and

10 Bq g^{-1} Ra 228 ~ 3 μSv hr^{-1}, resp.

5.6 Sludge from oil and gas exploitation: Shipment by road tanker from sludge pond to processing plant on road

Scenario description:

1. Loading of road tanker with siphon pipe
2. Transport to processing plant

Table 5.15 Specific activities in sludge

Material	Specific activity [Bq g^{-1}]				Source
	Ra 226	**Pb 210**	**Ra 228**	**Th 228**	
Sludge	6 30 – 60 (5 %) 12 – 30 (10 %) < 12 (85 %)	5	4 20 – 40 (5 %) 8 – 20 (10 %) < 8 (85 %)	5.5	Mean* /GEL 03/
Exempt limit for nuclide vector at Gommern gas field	13.2	7.4	5.2	6.8	
* values used for dose calculation					

The total amount of sludge (dry weight) is about 50 – 250 t yr^{-1} /WEI 05/.

Table 5.16 Parameters and assumptions applied for dose calculation

Topic	Warehouseman	Road tanker driver
External exposure		
Hours per journey / loading	6 hours per day for loading of road tanker	8 hours per day
Journeys per year	-	60
Hours worked per year	500	600 (incl. 240 hr empty drive)
Shielding (steel), cm		0.5
Distance from load, m		1.0 (240 hr)
Distance from sludge pond, m	1.0	3.0 (120 hr)
Dust inhalation		
No process-related dust emergence due to wet condition of mud		
Radon-222 inhalation		
No measurable Radon release		

5.7 Coal ash: Shipment of coal ash from ash storage area to landfill on road

Scenario description:

1. Loading of truck by front-end loader
2. Bulk cargo shipment by truck form storage area to landfill
3. Tilting of ash from truck at landfill storage area

Table 5.17 Specific activities in fly and bottom ash of coal combustion

Material*	**Specific activity [Bq g^{-1}]**		**Source**	**Remarks**
	Ra 226	**Th 232**		
Fly ash	0.1 – 1.9 0.4 0.11 (0.20)	0.05 – 1.1 0.2 0.09 (0.16)	/GRS 02/ /GIG 02/ /GEL 06/	Equilibrium is assumed regardless the occasional enrichment of volatile nuclides (Pb 210, Po 210)
Bottom ash	0.1 – 0.3 0.10 (0.17)	0.05 – 0.3 0.08 (0.12)	/GRS 02/ /GEL 06/	Equilibrium is assumed regardless the occasional depletion of volatile nuclides (Pb 210, Po 210)
* total quantity of fly ash: 1.2 E07 t/yr total quantity of bottom ash: 4.4 E06 t/yr				

Table 5.18 Values of specific activities used for dose calculation

Material	**Specific activity [Bq g^{-1}]**	
	U_{nat}	**Th_{nat}**
Ash from coal combustion	0.2	0.1

Table 5.19 Parameters and assumptions applied for dose calculation

Topic	Front-end loader driver	Truck driver	Warehouseman (at landfill)
External exposure			
Hours per journey / loading	6 hr d^{-1} for truck loading	6 per day	3 hr d^{-1} close to the truck
Journeys per year	100	100	150
Hours worked per year	600	600 (incl. 250 hr empty trip)	450
Shielding (steel), cm	1.5	0.5	
Distance from bulk shipment, m		1.0	2.0
Distance from storage area, m	1.0	5.0	
Dust inhalation			
Dust concentration, mg m^{-3}	0.5 (600 hr/yr)	0.5* / 0.05	0.5 (450 hr/yr)
Hours worked per year at area with enhanced dust concentration	600	100	450
Radon-222 inhalation			
Emanation rate	0.2		
Density of material, g cm^{-3}	1.5		
Radon diffusion coefficient, m^2 s^{-1}	2.0 E-06		
Deposit thickness, m	3.0		
Area of storage site, m^2	5,000		
Hours worked per year at area with enhanced Radon activity	600	200	450

* it is assumed that the truck driver stays close to the storage area where the dust concentration is enhanced

5.8 Uranium ore: Shipment of waste rock material form waste rock pile to open pit on road

Scenario description:

1. Loading of dump truck by front-end loader

2. Bulk cargo shipment with dump truck form waste rock pile to open pit

The mean specific activity of nuclides of Uranium –Radium - decay chain in waste rock material is 0.5 Bq g^{-1} (0.1 – 1.0 Bq g^{-1}) (legacies of former Uranium mining in Saxony and Thuringia). The mean specific Ra 226 activity of 0.5 Bq g^{-1} corresponds with a γ-dose rate of about 250 nSv hr^{-1} at a distance of 1 m.

Table 5.20 Parameters and assumptions applied for dose calculation

Topic	**Front-end loader driver**	**Dump truck driver**	**Worker (at storage site)**
External exposure			
Hours per journey / loading	8 hr d^{-1} for truck loading	8 hr d^{-1}	4 hr d^{-1} close to the dump truck
Journeys per year	150	150	150
Hours worked per year	1,200	1,200	600
Shielding (steel), cm	2.0	3.0	
Distance from bulk shipment, m		1.5	1.0
Dust inhalation			
Dust concentration, mg m^{-3}	0.2 (1,200 hr yr^{-1})	0.2* / 0.1	0.2 (600 hr yr^{-1})
Hours worked per year	1,200	400 / 800	600
Radon-222 inhalation			
Emanation rate	0.2		
Density of material, g cm^{-3}	2.0		
Radon diffusion coefficient, $m^2 s^{-1}$	2.0 E-06		
Deposit thickness, m	3.0		
Contaminated area, m^2	50,000		
Hours worked per year at area with enhanced Rn 222 activity	600	200	450
* the dust concentration is only slightly elevated due to required active dust suppression measures at dry weather conditions			

5.9 Zircon silicate (Pegmatite) or oxide (Baddeleyite): Bulk cargo from ship to processing plant on road

Scenario description:

1. Debarkation of raw materials by means of belt loader and interim storage at storage area
2. Loading of trucks with raw materials by means of front-end loader from storage area at harbour
3. Transport of bulk material from storage area to processing plant (ore mill)

Table 5.21 Specific activities in Pegmatite and Baddeleyite

Material*	Specific activity [Bq g^{-1}]		Source	Remarks
	U_{nat}	Th_{nat}		
Pegmatite	**3.0**	**0.6**	/GRS 02/	Mean values for dose calculation
	3.2 – 3.8	0.8 – 1.1	/CAL 08/	Data from Australia
	4.4	0.6	/FAT 04/	South Africa
	3.5	0.55	/FAT 04/	Italy
	2.1	0.46	/FAT 04/	Ukraine
Baddeleyite	**7.0**	**0.8**	/GRS 02/	Mean values for dose calculation
	11.5	1.8	/FAT 04/	South Africa
	4.3	0.42	/FAT 04/	Ukraine
* total quantity of milled Zircon sand: 15,000 t yr^{-1}				

Table 5.22 Parameters and assumptions applied for dose calculation

Topic	**Front-end loader driver**	**Truck driver**	**Belt loader operator**	**Dock worker**
External exposure				
Hours per journey / loading	8 hr d^{-1} for truck loading	8 hr d^{-1}	8	8
Journeys per year		10		
Hours worked per year	80	80	80	80
Shielding (steel), cm	1.5	0.5		
Distance from bulk shipment, m	1.0 (35 hr)	1.0 (35 hr)	1.0 (20 hr)	1.0 (20 hr)
Distance from storage area, m	1.0 (35 hr)	5.0 (10 hr)		
Distance from cargo hold, m			1.0 (60 hr)	1.0 (60 hr)
Dust inhalation				
Dust concentration, mg m^{-3}	0.5	0.5* / 0.05	0.5 (80 hr yr^{-1})	0.5 (80 hr yr^{-1})
Hours worked per year at area with enhanced dust concentration	80	10	80	80
Radon-222 inhalation				
Emanation rate	0.2			
Density of material, g cm^{-3}	3.0			
Radon diffusion coefficient, m^2 s^{-1}	2.0 E-06			
Deposit thickness in cargo hold, m			2.0	
Area of cargo, m^2			50	
Deposit thickness in storage area, m	2.0			
Area of deposits, m^2	100			
Hours worked per year in area with enhanced Rn 222 activity	80	10	80	80
* it is assumed that the truck driver stays close to the storage area where the dust concentration is enhanced				

The conversion factor g_{ext} (ratio between the specific activity of Ra 226 or Ra 228 to the γ-dose rate at 1 m height; see Chapter 4.1) was used.

5.10 Zircon silicate (Pegmatite) or oxide (Baddeleyite): Shipment from processing plant to foundry on road

Scenario description:

1. Loading of truck with big bags by means of fork lift truck at storage area
2. Transport of big bags from ore mill to foundry

Table 5.23 Parameters and assumptions applied for dose calculation

Topic	Fork-lift truck driver	Truck driver	Warehouseman
External exposure			
Hours per journey / loading	2 hr d^{-1} for truck loading	8 hr (4 hr with empty truck)	2 hr d^{-1} close to the big bags
Journeys per year	100	100	100
Hours worked per year	200	800	200
Shielding (steel), cm		0.5	
Distance from big bags, m	1.0	1.0 (400 hr)	0.5
Dust inhalation			
No enhanced dust concentration			
Radon-222 inhalation			
Emanation rate	0.2		
Density of material, g cm^{-3}	3.0		
Radon diffusion coefficient, m^2 s^{-1}	2.0 E-06		
Deposit thickness, m	1.0 (big bag height)		
Big bag surface (50 big bags of 1.0 m^2 each), m^2	50		
Hours worked per year in area with enhanced Rn 222 activity	100	0	200

The mean values of specific activities of U_{nat} and Th_{nat} in Baddeleyite and Pegmatide used for dose calculations see Table 5.21.

Table 5.24 Ratio of γ-dose rate at distance x (m) vs. γ-dose rate on the surface of big bags

Distance [m]	**Value**
0.5	0.65
1.0	0.50
2.0	0.30

5.11 Zircon silicate (Pegmatite) or oxide (Baddeleyite): Shipment of milled zirconium from harbour in Germany to harbour in Iran

1. Ship loading with big bags by means of deck crane
2. Sea transport from Germany to Iran

Table 5.25 Specific activities in milled Zircon sand imported from Germany in 1999 – 2001

Material*	**Specific activity [Bq g^{-1}]**		**Source**	**Remarks**
	U_{nat}	Th_{nat}		
Baddeleyite	2.24	0.47	/FAT 04/	Mean values for dose calcula-tion weight: 60 t
Pegmatide	2.70	0.59	/FAT 04/	Mean values for dose calcula-tion weight: 20 t

Table 5.26 Parameters and assumptions applied for dose calculation

Topic	Crane operator	Ship´s crew
External exposure		
Hours per loading	3 hours	
Journeys per year	-	1 (20 d)
Distance from load, m	5.0 (3 hr for loading and uploading, each)	2.0 (2 hr d^{-1})
Dust inhalation		
No enhanced dust concentration		
Radon-222 inhalation		
Emanation rate		0.2
Density of material, g cm^{-3}		3.0
Radon diffusion coefficient, m^2 s^{-1}		2.0 E-06
Deposit thickness, m		2.0 (2 big bags one upon the other)
Big bag surface (30 big bags of 1.0 m^2 each), m^2		15
Hours worked per year in area with enhanced Rn 222 activity		40

Ratio of γ-dose rate at distance x (m) vs. γ-dose rate at surface of big bags see Table 5.24.

5.12 Titanium dioxide raw materials (Ilmenite, Rutile): Shipment from ship to plant on road

1. Debarkation of raw materials by means of belt loader and interim storage at storage area

2. Loading of trucks with raw materials by means of front-end loader from storage area at harbour

3. Transport of bulk material from storage area to plant

Table 5.27 Specific activities in ore

Material*	Specific activity [Bq g^{-1}]		Source	Remarks
	U_{nat}	Th_{nat}		
Ilmenite	0.1 – 0.5 0.03 – 0.7 0.25	0.5 – 1.9 0.03 – 6.0	/CAL 08/ /POF 02/ /ICP 02/	Data from Australia
Rutile	0.1 – 0.8 1.0	0.2 – 0.6	/CAL 08/ /ICP 02/	Data from Australia
Monazite	400 (max.)		/GRS 02/	Disused in Germany
* total quantity of raw materials containing Titanium imported to Germany: 420,000 t yr^{-1} /GEL 06/				

Table 5.28 Values of specific activities used for dose calculation

Material	Specific activity [Bq g^{-1}]	
	U_{nat}	Th_{nat}
Ilmenite	0.5	2.0
Rutile	0.8	0.5

Table 5.29 Parameters and assumptions applied for dose calculation

Topic	Front-end loader driver	Truck driver	Belt loader operator	Dock worker
External exposure				
Hours per journey / loading	8 hr d^{-1} for truck loading	8 hr d^{-1}	8 hr d^{-1}	8 hr d^{-1}
Journeys per year		25		
Hours worked per year	200	200 (90 with empty truck)	200	200
Shielding (steel), cm	1.5	0.5		
Distance from bulk shipment, m	1.0 (90 hr)	1.0 (90 hr)		
Distance from storage area, m	1.0 (90 hr)	5.0 (20 h)		
Distance from cargo hold, m			0.5 (150)	0.5 (150)
Dust inhalation				
Dust concentration, mg m^{-3}	0.5	0.5* / 0.05	0.5	0.5
Hours worked per year in area with enhanced dust concentration	200	20	200	200
Radon-222 inhalation				
Emanation rate	0.2			
Density of material, g cm^{-3}	3.0			
Radon diffusion coefficient, m^2 s^{-1}	2.0 E-06			
Deposit thickness in cargo hold, m			2.0	
Area of cargo, m^2			50	
Deposit thickness in storage area, m	2.0			
Area of deposits, m^2	100			
Hours worked per year in area with enhanced Rn 222 activity	200	10	200	200

* it is assumed that the truck driver stays close to the storage area where the dust concentration is enhanced

The ratio of γ-dose rate at distance x (m) vs. γ-dose rate at surface of the bulk shipment see Table 5.24.

5.13 Filter gravel from waterworks: Shipment from water work to landfill on road

1. Loading road tanker with siphon pipe

2. Transport to landfill

Table 5.30 Values of specific activities used for dose calculation /FEI 09/

Material	Specific activity in Bq kg^{-1} (dry weight)				
	Ra 226	U 238	Pb 210	Ra 228	Th 228
Filter material					
Mean value	1,398	20.9	32.6	443	566
Maximum	1,640	35	62	640	700
Dust					
Mean value	4,750	-	480	1,025	1,475
Maximum	5,300	34	590	1,200	1,700

Data from waterwork “Tegel”, Berlin, Germany

The mean and maximum γ-dose rate measured in the filter hall of the waterwork “Tegel” above gravel beds amounted to

H_x = 240 nSv hr^{-1} (n = 20) H_{max} = 271 nSv hr^{-1} in 1.00 m height, and
H_x = 311 nSv hr^{-1} (n = 20) H_{max} = 336 nSv hr^{-1} in 0.10 m height.

The road tanker driver carries out 10 journeys per year of 4 hours each (2 hours of each journey with empty tank). The cabine shielding is 0.3 cm and the distance of the driver to the load is 1.0 m.

6 Results and evaluation of dose calculation

In the following the results of dose calculation are presented for each scenario and will be evaluated with respect to their allocation as „exempt material“ or LSA I (or SCO-I) material.

The exemption values listed in TS-R-1 for transport of radioactive materials are related to a dose of 10 μSv yr^{-1}, i.e. on the same basis as for the clearance of radioactive material from the provision of radiation protection legislation (according to BSS). Nevertheless, the scenarios used for the calculation of clearance values in BSS do not agree with typical transport scenarios. The latter considers primary the external exposure while the ingestion path is excluded and the inhalation of Radon and dust applies only for a comparably short time (loading and unloading) of the total time of consideration.

Furthermore, the considered time for the transportation of the mentioned transport scenarios is based on the total amount of a material which is transported per year in Germany. In most cases the dose to transport personnel was additionally calculated by means of normalized scenarios regarding an exposure time of 500 hr yr^{-1} as agreed at RCM 2.

6.1 Bulk cargo of Tantalum raw materials from railcar yard to plant

According to the data used for the calculation of dose to the yard worker and the truck driver by bulk cargo of tantalum raw materials (see Table 5.3) all kind of raw material, except for tin slag, exceeds the 10fold activity concentration (U_{nat} + Th_{nat}) for exempt material, i.e. these materials fall under the provision of TS-R-1 or the equivalent national regulation on safe transport of radioactive material.

As the results show, the doses to yard worker and truck driver would exceed the dose limit for a person of the population of 1 mSv yr^{-1} by unpackaged LSA I transport of Microlyte having the highest activity concentration of all kind of Tantalum raw materials.

In case of a bulky shipment of Tantalum raw material having the 10fold activity concentration (U_{nat} + Th_{nat}) for exempt material the calculated dose (see Table 6.1) for the scenario described in Table 5.3 would lead to a dose rate of the yard worker of about 0.5 mSv yr^{-1} with equal shares for external exposure and exposure by inhalation of dust. Contrary, the total dose to druck driver is about 0.15 mSv yr^{-1} for the given scenario due to the smaller contribution of the inhalation dose to the total dose.

Nevertheless, according to the information given by the Tantalum-Niobium International Study Center nowadays no bulk transport of Tantalum raw material takes place worldwide to avoid high inhalation doses to the workers in the ore mill. The raw materials are processed to concentrates in the milling facilities and put into drums or big bags at the production site before shipment. Accordingly, the dose to the transport personnel would only result from external exposure by γ-radiation while the internal dose by inhalation of dust is largely suppressed.

Table 6.1 Calculated dose to transport personnel resulting from the bulk cargo of Tantalum raw materials

Material	U_{nat} [Bq kg^{-1}]	Th_{nat} [Bq kg^{-1}]	Personnel	Hours worked per year	Dust $H_{(Inh,j)}$ [mSv yr^{-1}]	Radon $H_{(Inh,j)}$ [mSv yr^{-1}]	external $H_{(E,j)}$ [mSv yr^{-1}]	Total dose [mSv yr^{-1}]
Microlyte	30,000	10,000	Yard worker	500	9.80E-01	8.60E-03	1.05E+00	2.04E+00
Tantalum Raw Materials	7,500	2,500		500	2.45E-01	2.15E-03	2.63E-01	5.10E-01
Microlyte	30,000	10,000	Truck driver	250+100	1.96E-01	1.72E-03	4.59E-01	6.57E-01
Tantalum Raw Materials	7,500	2,500		250+100	4.05E-02	3.44E-04	1.15E-01	1.56E-01

6.2 Bulk cargo of raw phosphate from ship to plant

As can be seen in the following Table 6.2 the dose to the personnel is in the order of some 10 µSv yr^{-1} basing upon the sum activity of 1.6 Bq g^{-1} (1.5 Bq g^{-1} U_{nat} + 0.1 Bq g^{-1} Th_{nat}). The highest external dose received the belt loader operator regardless the shorter exposure time as given for the front-end loader driver. This is mainly caused by the direct contact with the material and the missing shielding. On the other hand, the highest total dose was received by the front-end loader driver due to the comparable high portion of inhalation dose to the total dose and the longer exposure time as given for the belt loader operator.

Table 6.2 Calculated dose to transport personnel resulting from the bulk cargo of raw phosphate

Material	U_{nat} [Bq kg^{-1}]	Th_{nat} [Bq kg^{-1}]	Personnel	Hours worked per year	Hours with enh. dust conc.	External $H_{(E,j)}$ [mSv yr^{-1}]	Dust $H_{(Inh,j)}$ [mSv yr^{-1}]	Radon $H_{(Inh,j)}$ [mSv yr^{-1}]	Total dose [mSv yr^{-1}]
Raw phosphate	**1,500**	**100**	**Belt loader operator**	200	200	3.96E-02	7.96E-03	6.85E-04	4.82E-02
			Front-end loader driver	500	500	3.07E-02	1.99E-02	1.71E-03	5.23E-02
			Truck driver		100	9.90E-04	3.98E-03	3.43E-04	4.14E-02
			Truck driver	250		3.61E-02			

The dose of the transport personnel which would result from the same scenario of transport of raw phosphate having a sum activity (U_{nat} + Th_{nat}) of 10 Bq g^{-1} (10fold limit for exempt material) would be about 0.3 mSv yr^{-1}. The share of inhalation dose is nearly 20 % to the total dose and is therefore also not negligible. The resulting dose is comparable to the dose resulting from the scenario given for bulky transport of Tantalum raw materials. Contrary to these materials no raw phosphate is known which reaches the 10fold activity concentration (U_{nat} + Th_{nat}) for exempt material. Referring to literature the maximum activity concentration of raw phoshate is about 5.0 Bq g^{-1} U_{nat} and 0.2 Bq g^{-1} Th_{nat}, i.e. the doses given in Table 6.3 do not occur in practice.

Table 6.3 Calculated dose to transport personnel resulting from the bulk cargo of raw phosphate basing upon the 10fold activity concentration (U_{nat} + Th_{nat}) for exempt material

Material	U_{nat} [Bq kg^{-1}]	Th_{nat} [Bq kg^{-1}]	Personnel	Hours worked per year	Hours with enh. dust conc.	External $H_{(E,j)}$ [mSv yr^{-1}]	Dust $H_{(Inh,j)}$ [mSv yr^{-1}]	Radon $H_{(Inh,j)}$ [mSv yr^{-1}]	Total dose [mSv yr^{-1}]
Raw phosphate	9,000	600	Belt loader operator	200	200	2.38E-01	4.78E-02	4.11E-03	2.90E-01
			Front-end loader dri-ver	500	500	1.84E-01	1.19E-01	1.03E-02	3.13E-01
			Truck driver		100	5.94E-03	2.39E-02	2.06E-03	2.49E-01
			Truck driver	250		2.17E-01			

6.3 Shipment of contaminated pipes in container from scrap yard to un-derground repository

The results of dose calculation in the following Table 6.4 are based on γ-spectro-metric measurements of scales from a gas field in Saxony Anhalt, while Table 6.5 presents the doses calculated for the 10fold exempt limit by means of the formula on para. 405 of TS-R-1.

Even for the first dose calculation basing upon a sum activity concentration of about 300 Bq g^{-1} (sum of long-lived nuclides according to Table 5.12) the calculated dose for all workers is comparably low despite the high total activity. This results mainly from the short, but realistic exposure time and the absence of all other exposure paths but the external exposure by γ-radiation.

Table 6.4 Calculated dose to transport personnel resulting from shipment of contaminated pipes in container by means of a sum activity of 300 Bq g^{-1}

Personnel	Hours worked per year	Shielding (steel) [cm]	Distance [m]	External $H_{(E,j)}$ [mSv yr^{-1}]
Fork-lift truck driver	12.5		1.0	6.98E-03
Truck driver	100	1.00	1.5	1.15E-02
Warehouseman at container	50		0.0 / 0.5	7.21E-02
Warehouseman at tubes	100		0.0 / 0.5	4.88E-02
Warehouseman, total	150			**1.21E-01**

Table 6.5 Calculated dose to transport personnel resulting from shipment of contaminated pipes in container by means of a sum activity of 40 Bq g^{-1} (calculated 10fold exempt value according to para. 405 of TS-R-1)

Personnel	Hours worked per year	Shielding (steel) [cm]	Distance [m]	External $H_{(E,j)}$ [mSv yr^{-1}]
Fork-lift truck driver	12.5		1.0	9.21E-04
Truck driver	100	1.00	1.5	1.52E-03
Warehouseman at container	50		0.0 / 0.5	9.52E-03
Warehouseman at tubes	100		0.0 / 0.5	6.44E-03
Warehouseman, total	150			**1.60E-02**

Assuming an exposure time of 500 hours per year for the warehouseman the external dose would be about 5.3 E-02 mSv yr^{-1} corresponding to a Ra 226 activity concentration of 13.2 Bq g^{-1} (resulting from the sum activity with nuclide proportion given in Table 5.12).

6.4 Shipment of unpackaged pipes from drilling platform to pipe rack

This scenario and the used assumtions and parameters are typically for such kind of work. Despite the low dose given in the Table 6.6 all these transports are carried out under the German transport regulations /ADR 09/ because the activity concentrations exceed in most cases the 10fold value for exempt material.

The dose calculation is based on the values of activity concentrations given in Table 5.12 (upper line), i.e. 100 Bq g^{-1} Ra 226 and 40 Bq g^{-1} Ra 228.

Table 6.6 Calculated dose to transport personnel resulting from shipment of unpackaged pipes (scenario according to Table 5.10)

Personnel	Hours per pipe change	Shielding (steel) [cm]	Distance [m]	External $H_{(E,j)}$ [mSv/pipe change]
Fork-lift truck driver	20		1.0	1.12E-02
Truck driver	20	1.00	1.5	3.50E-03
Crane operator	10		3.0	1.86E-03
Floorman	10		0.5	3.47E-03

Assuming an exposure time of 200 hours per year for the fork lift truck driver and a Ra 226 activity concentration of 13.2 Bq g^{-1} (resulting from the sum activity of 40 Bq g^{-1} with nuclide ratio given in Table 5.12) the external dose would be 1.5 E-02 mSv yr^{-1}.

6.5 Shipment of scales in drums or big bags from storage area to processing plant

This scenario is realistic for both, the radionuclide concentrations used for dose calculation and the transport time per year. These transports are carried out under /ADR 09/ provision because the activity concentrations exceed in most cases the 10fold activity concentration for exempt material and the doses to the truck driver and the warehouseman exceed sometimes the dose limit for a member of the public of 1 mSv yr^{-1}.

Table 6.7 Calculated dose to transport personnel resulting from shipment of scales in drums or big bags (parameters and assumptions according to Table 5.12 and Table 5.13)

Material	Personnel	Hours worked per year	Shielding (steel) [cm]	Distance [m]	External $H_{(E,i)}$ [mSv yr^{-1}]
Crude oil & and natural gas scales	**Fork-lift truck driver**	40		1.0	1.92E-01
	Truck driver	80	0.50	1.0	2.80E-01
	Warehouseman	20 / 20		0.0 / 0.5	5.76E-01
Natural gas scales; maximum exempt limit: 94 Bq g^{-1} Ra 226	**Fork-lift truck driver**	40		1.0	5.60E-02
	Truck driver	80	0.50	1.0	8.18E-02
	Warehouseman	20 / 20		0.0 /0.5	1.68E-01

The results of dose calculation in Table 6.7 due to transport of crude oil and natural gas scales is based on data of activity concentration in Table 5.12 while for natural gas scales the 10fold Ra 226 activity concentration of 94 Bq g^{-1} (calculated by means of para. 405 of TS-R-1) was derived from the extreme ratio between the Ra 228 and Ra 226 activity concentration reported by /KOL 85/.

At first view the results in Table 6.7 seem to be contradictionary because in both cases the Ra 226 activity concentration is all about the same (100 Bq g^{-1} and 94 Bq g^{-1}, resp.). But while the scales with a mean ratio between Ra 226 and Ra 228 (upper line) contain additionally 40 Bq g^{-1} Ra 228 (and 50 Bq g^{-1} Th 228) which contribute significantly to the total external dose, the natural gas scales with a maximum ratio between Ra 226 and Ra 228 (lower line) contain only less than 1 Bq g^{-1} Ra 228 without relevance to the external dose.

The following Table 6.8 contains the results of dose calculation for an assumed working time of 500 hours per year for each of the three different workers (with the same assumptions for shielding and distance to the drums).

Table 6.8 Calculated dose to transport personnel resulting from shipment of scales in drums or big bags for a working time of 500 hours

Material	Personnel	External $H_{(E,j)}$ [mSv yr^{-1}]
Crude oil & and natural gas scales	**Fork-lift truck driver**	3.16E-01
	Truck driver	2.31E-01
	Warehouseman	9.50E-01
Natural gas scales; maximum exempt limit: 94 Bq g^{-1} Ra 226	**Fork-lift truck driver**	7.00E-01
	Truck driver	5.11E-01
	Warehouseman	2.10E-00

As the results show, the dose to the warehouseman by handling of drums filled with scales of 94 Bq g^{-1} Ra 226 - which would correspond to the 10fold limit of activity concentration of Ra 226 calculated by means of para. 405 of TS-R-1 - would exceed the dose limit of 1 mSv yr^{-1} for members of the public. Nevertheless, this scenario is unreaslistic due to the small amount of such kind of scales. It is estimated that the total amount of scales with such a high Radium activity concentration is less than one ton or two drums per year in Germany.

6.6 Shipment of sludge from oil and gas exploitation with road tanker from sludge pond to processing plant

This scenario is realistic for both, the radionuclide concentrations used for dose calculation and the transport time per year. These transports are carried out under the provision of /ADR 09/ as LSA I although only in 15 % of sludge (see Table 5.15) the 10fold exemption limit (calculated by means of the formula in para. 405 of TS-R-1) is exceeded.

This scenario is the same as described in Chapter 5.5 but with lower activity concentrations according to Table 5.15.

Table 6.9 Calculated dose to transport personnel resulting from shipment of sludge from oil and gas exploitation with road tanker

Personnel	Hours worked per year	Shielding (steel) [cm]	Distance [m]	External $H_{(E,j)}$ [mSv yr^{-1}]
Warehouseman	500			2.11 E-02
Road Tanker Driver	240 / 120	0,50	1,0 / 3.0	9.06 E-03

6.7 Shipment of coal ash from ash storage area to landfill

In Germany the activity concentrations of natural radionuclides in coal ash do not exceed the limits given for exempt materials in Table 2 of TS-R-1. Therefore all transports of coal ash do not fall under the provisions of the German regulation on transport of radioactive materials /ADR 09/.

Table 6.10 Calculated dose to transport personnel resulting from shipment of coal ash (according to activity concentrations on Table 5.18)

Person-nel	Hours worked per year	Shielding (steel) [cm]	Dis-tance [m]	Dust concen-tration [mg m^{-3}]	Hours with enh. dust conc.	External $H_{(E,j)}$ [mSv yr^{-1}]	Dust $H_{(Inh,j)}$ [mSv yr^{-1}]
Front-end loader driver	600	1.50	1.0	0.50	600	7.81E-03	4.38E-03
Truck driver	250 / 100	0.50	1.0 / 5.0	0 / 0.50	0 / 100	7.88E-03	7.30E-04
Ware-house-man (at land-fill)	450		2.0	0.50	450	5.10E-03	3.29E-03

6.8 Shipment of waste rock material from uranium mining

The results given in Table 6.11 are based on the scenario described in Chapter 5.8. The dose calculation was carried out without the exposure by inhalation of Rn 222 and its short-lived decay products due to enhanced outdoor radon concentration of about 200 Bq m^{-3} where only occupationally exposed personnel gains access to this area.

Despite the annual working time of 1,200 hours the calculated external dose is comparably low due to the attenuation of the γ-dose rate by the high shielding factor of the driver´s cabin of the front-end loader (capacity per bucket 30 t) and dump truck as well as the distance to ground of about 3 m of driver´s seat of the dump truck (load about 120 t). In addition, the mean activity concentration of U_{nat} is less than 1 Bq g^{-1}, i.e. below the limit of exempt material according to Table 2 of TS-R-1.

In Germany, all shipments of residues from former Uranium mining and milling are carried out under the provisions of the German regulation on transport of radioactive materials /ADR 09/.

Table 6.11 Calculated dose to transport personnel resulting from shipment of waste rock material from uranium mining

Personnel	Hours worked per year	Shiel-ding (steel) [cm]	Dis-tance [m]	Dust concen-tration [mg/m³]	Hours with enh. dust conc.	External $H_{(E,i)}$ [mSv/yr]	Dust $H_{(Inh,i)}$ [mSv/yr]	Total dose [mSv/yr]
Front-end loader driver	1,200	2.00	1.0	0.20	1,200	1.94E-02	6.00E-03	2.54E-02
Dump truck driver	1,200	3.00	1.5	0.20 / 0.10	400 / 800	9.87E-03	4.00E-03	1.39E-02
Labourer (at storage site)	600		1.0	0.20	600	4.05E-02	3.00E-03	4.35E-02

6.9 Bulk cargo of Zircon raw materials from ship to processing plant

The results given in Table 6.12 are based on the parameters and assumptions described in Table 5.21 and Table 5.22. The total dose for all workers is less than 0.1 mSv yr^{-1} despite the activity concentrations of 7.0 Bq g^{-1} U_{nat} and 0.8 Bq g^{-1} Th_{nat} (i.e. about the 8fold activity concentration for exempt material) used for dose calculation. On the other hand, the exposure time is comparably low but realistic due to the total amount of imported Zircon raw material of some 10thousend tons per year.

Nevertheless, if assuming conservatively the 5fold exposure time and the 10fold exempt limit the total dose to belt loader operator and dock worker would be in the range of about 0.5 mSv yr^{-1} with a share of about 0.4 mSv yr^{-1} for external exposure. Referring to the recent practice the Zircon raw material is commonly shipped in big bags just as described for Tantalum raw materials. In comparison with the results given in Table 6.1 for exposure by transport of Tantalum raw material with the 10fold exempt activity concentration the external exposure is nearly the same in both cases. This was expected because the external exposure by γ-radiation is caused by short lived γ-ray emitting decay products of Ra 226 and Ra 228 only.

Table 6.12 Calculated dose to transport personnel resulting from bulk cargo of Zircon raw materials

Personnel	Hours worked per year	Shielding (steel) [cm]	Distance [m]	Hours with enh. dust conc.	external $H_{(E,j)}$ [mSv yr^{-1}]	Dust $H_{(Inh,j)}$ [mSv yr^{-1}]	Total dose [mSv yr^{-1}]
Front-end loader driver	70	1.50	1.0 (bulk shipment)	80	2.14E-02	1.55E-02	3.69E-02
Truck driver	35 / 10	0.50	1.0 / 5.0	10	2.56E-02	1.93E-03	2.75E-02
Belt loader operator	80		1.0	80	7.87E-02	1.55E-02	9.42E-02
Dock worker	80		1.0	80	7.87E-02	1.55E-02	9.42E-02

6.10 Shipment of milled Zircon from processing plant to foundry

The results given in Table 6.13 are based on the parameters and assumptions described in Table 5.23 and Table 5.24. The transport of milled Zircon sand to foundries is always carried out as packaged load, in such a way only the external exposure by γ-radiation must be taken into account. The calculated dose to the truck driver amounts to about 0.15 mSv yr^{-1} by means of the activity concentrations of 7.0 Bq g^{-1} U_{nat} and

0.8 Bq g^{-1} Th_{nat} (i.e. about the 8fold value for exempt material), in case of material with the 10fold exempt concentration the external dose would be less than 0.20 mSv yr^{-1}.

Table 6.13 Calculated dose to transport personnel resulting from shipment of packaged milled Zircon sand

Material	**U_{nat} [Bq/kg]**	**Th_{nat} [Bq/kg]**	**Personnel**	**Hours worked per year**	**Shielding (steel) [cm]**	**Distance [m]**	**External $H_{(E,i)}$ [mSv yr^{-1}]**
Baddeleyite	7,000	800	**Fork-lift truck driver**	200		1.0	9.84E-02
			Truck driver	400	0.50	1.0	1.44E-01
			Warehouseman	200		0.5	1.28E-01

6.11 Shipment of milled Zircon from harbour in Germany to harbour in Iran

The dose calculation is based on a realistic data set reported by /FAT 04/. According to the data given in Table 5.25 the total amount of milled Zircon sand was only 80 t, subsequently the dose to personnel is less than 1 μSv yr^{-1} despite the 3fold limit for exempt material (U_{nat} + Th_{nat}).

Table 6.14 Calculated dose to transport personnel resulting from shipment of packaged Zircon sand from harbour in Germany to harbour in Iran

Material	U_{nat} [Bq kg^{-1}]	Th_{nat} [Bq kg^{-1}]	Personnel	Hours worked per year	Shielding (steel) [cm]	Dis-tance [m]	Externa, $H_{(E,i)}$ [mSv]	Radon $H_{(Inh,i)}$ [mSv]
Pegmatide	2,700	590	**Crane operator**	3 h		5.0	9.03E-05	
			Ship´s crew	40 h		2.0	5.16E-03	1.12E-05
Baddeleyit e	2,240	470	**Crane operator**	3 h		5.0	7.42E-05	
			Ship´s crew	40 h		2.0	4.24E-03	9.31E-06

6.12 Shipment of Titanium dioxide raw materials from ship to plant

The results given in Table 6.15 are based on the parameters and assumptions described in Table 5.28 and Table 5.29. As can be seen in Table 6.15 the total dose for all workers is less than 0.1 mSv yr^{-1}. The external dose by γ-radiation contributed at least by 2/3 of the total dose (front-end loader driver) while the remaining share to the total dose was mainly caused by inhalation of contaminated dust.

Due to the huge amount of imported Titanium containing raw materials of about 420,000 t yr^{-1} /GEL 06/ an interim outdoor storage of some hundreds m^3 was assumed from which Radon gas could emanate. Nevertheless, the calculated dose to personnel by inhalation of Rn 222 and its short-lived decay products was negligible despite the activity concentration of 0.8 Bq g^{-1} U_{nat}.

Table 6.15 Calculated dose to transport personnel resulting from bulk shipment of Titanium dioxide raw materials

Material	U_{nat} [Bq kg^{-1}]	Th_{nat} [Bq kg^{-1}]	Personnel	Hours worked per year	Shielding (steel), [cm]	Distance, [m]	Dust concentration [mg m^{-3}]	Hours with enh. dust conc.	External, $H_{(E,i)}$ [mSv yr^{-1}]	Dust, $H_{(Inh,i)}$ [mSv yr^{-1}]	Radon, $H_{(Inh,i)}$ [mSv yr^{-1}]	Total dose [mSv yr^{-1}]
Ilmenite	500	2,000	**Front-end loader driver**	180	1.50	1,0	0.5	200	2.34E-02	1.17E-02	6.88E-05	3.52E-02
			Truck driver	90 / 20	0,50 / -	1.0 / 5.0	0.05 / 0.5	20	2.80E-02	1.17E-03	6.88E-06	2.92E-02
			Belt loader operator	150		0.5	0.5	200	9.07E-02	1.17E-02	3.45E-05	1.02E-01
			Dock worker	150		0.5	0.5	200	9.07E-02	1.17E-02	3.45E-05	1.02E-01
Rutile	800	500	**Front-end loader driver**	180	1,50	1.0	0.5	200	1.04E-02	6.30E-03	1.10E-04	1.68E-02
			Truck driver	90 / 20	0,50 / -	1.0 / 5.0	0.05 / 0.5	20	1.24E-02	6.30E-04	1.10E-05	1.25E-02
			Belt loader operator	150		0.5	0.5	200	4.02E-02	6.30E-03	5.53E-05	4.66E-02
			Dock worker	150		0.5	0.5	200	4.02E-02	6.30E-03	5.53E-05	4.66E-02

6.13 Shipment of spent filter gravel from water work to landfill

The results of dose calculation are based on the parameters and assumptions described in Section 5.13. The dose to the worker at the siphone pipe by inhalation of Rn 222 was calculated on the basis of measured in-door Rn 222 concentration as follows:

Table 6.16 Maximum dose to worker at siphon pipe by radon inhalation

Waterwork	Steady state factor f	Maximum doses* by inhalation of Rn 222 [mSv yr^{-1}]
Tegel	0.20	0.37
* related to the maximum annual exposure time of 300 hr yr^{-1}		

The external dose to the worker at the siphon pipe due to stay on the gravel is about 0.05 mSv yr^{-1} for 300 hours. The highest share of the total dose of this worker results from the inhalation of dust with 0.45 mSv yr^{-1} for 300 hours, i.e. nearly 10times higher as the external dose which is caused by the accumulation of the radionuclides in the dust fraction by a factor of 4 (see Table 5.30). Subsequently, the total dose for the worker at the siphon pipe is about 0.9 mSv yr^{-1} for 300 hours exposure time.

In practice, the exposure time is less than 100 hours per year for those kind of work. On the other hand this exposure scenario is no typical transport scenario, regardless that the worker at the siphon pipe loads a road tanker. To minimize the inhalation dose according to the ALARA principle it is recommended to replace the described dry method by a wet suction technique.

For the calculation of the dose to the road tanker driver it is assumed that the relationship between γ-dose rate and Ra 226 or Ra 228 activity concentration at the surface of the road tanker and in different distances is the same as described for containers. Contrary to the dose of the loading man the dose to the driver results from external exposure only. For the road tanker driver the external dose was calculated to 4 μSv yr^{-1} for an exposure time of 300 hours (thereof 150 hours with empty tank).

7 Summary and conclusions

For the calculation of the radiation exposure by shipment of NORM to transport personnel nine different NORM materials were selected and 13 exposure scenarios were defined. As far as possible measured values or literature data of activity concentrations of the relevant natural radionuclides, the exposure time per year and the performance of the transport (on road, train or ship as well as bulky or packaged) were taken. It is assumed that in every case the external exposure by γ-radiation is decisive, while for bulk transport also the dose to personnel by inhalation of dust and Radon 222 may contribute to the total dose. The dose calculation was additionally carried out for each kind of material with radioactive equilibrium by means of an exposure time of 500 hr yr^{-1} and the 10fold limit for exempt material.

For material with non-equilibrium within the Uranium-Radium decay chain and the Thorium decay chain the exposure to personnel was also determined on the basis of the calculated 10fold limits of activity concentration for exempt materials according to the formula in para. 405 of TS-R-1. Furthermore, the dose to transport personnel by transport of scales (in tubes or drums) was calculated for a Ra 226 activity concentration of 94 Bq g^{-1} and a Ra 228 activity concentration of 7 Bq g^{-1} resulting by application of the formula in para. 405 of TS-R-1 for extreme nuclide relations on scales from German oil and gas fields /KOL 85/.

In the report on hand only the exposure to transport personnel for incident free normal conditions of transport was calculated. According to the results of dose calculation for accident scenarios as well as for members of the public living along transport routes doses of less than 10 μSv yr^{-1} due to the transport of spilled materials were reported by the CRP participants of Brazil /LAV 08/ and Canada /CHA 07/.

The results of the described investigation on the calculation of dose to transport personnel are summarized as follows:

1. In case of bulky transport the dose by inhalation of dust contributes up to 50 % (normally 15 % – 25 %) to the total dose while the dose by inhalation of Rn 222 is in every case negligible. That is caused by the low potential of Radon emanation from the small surface of the spilled material, e.g. in comparison to huge waste rock heaps from Uranium mining.

2. In case of transport of packaged material with radioactive equilibrium the dose to personnel results from external exposure by γ-radiation only. That is solely caused by the activity concentration of Ra 226 and Ra 228, because γ-emitters occur always after these Radium isotopes in the concerning decay chains. Subsequently, the resulting dose to personnel by γ-radiation is nearly the same for all kind of NORM material if main parameters, as exposure time, shielding or distance to the load are agreeing, but the external dose increases with increasing share of the activity concentration of Ra 228 (Thorium decay chain) due to the higher intensity of its short lived γ-emitting decay products compared to those of Ra 226 (Uranium-Radium decay chain).

3. In case of NORM materials having no radioactive equilibrium within one or both decay chains the external exposure also depends from the activity concentration of these Radium isotopes only. For scales from oil and gas exploitation in Germany the two extreme nuclide ratios were found by /KOL 85/:

   – The first case concerns scales consisting exclusively of Ra 226 for which the value of the 10fold exempt concentration was calculated to 95 Bq g^{-1} by means of the formula in para. 405 of TS-R-1. The regrowing Pb 210 and Po 210 can be neglected because their concentration reaches a certain activity level only after a couple of years. If carrying out the dose calculation on the basis of 95 Bq g^{-1} Ra 226 for an exposure time of 500 hr the exposure to the personnel would be about 2 mSv yr^{-1}, i.e. twice as high as the dose limit for members of the public according to /SSV 01/.

   – The second case concerns scales consisting exclusively of Ra 228 for which the value of the 10fold exempt concentration was calculated to 16 Bq g^{-1} (sum activity) with 7 Bq g^{-1} Ra 228 and 9 Bq g^{-1} Th 228, respectively by means of the formula in para. 405 of TS-R-1, i.e. the calculated maximum Ra 228 activity concentration is nearly 14 times lower than those of Ra 226. That is caused by the presence of Th 228 which regrows from Ra 228 much faster than Pb 210 from Ra 226. Because the exempt limit for Th 228 is by a factor of 10 lower than that for Ra 228, for physical reasons it is excluded that the Ra 228 activity concentration may exceed its exempt limit of 10 Bq g^{-1} according to Table 2 of TS-R-1. Subsequently, the maximum dose to personnel would be always lower than 0.1 mSv yr^{-1}.

4. A special case concerns NORM residues from thermal processes such as filter dust and fly ash where only the high volatile natural radionuclides Pb 210 and Po 210 occur while the low volatile Uranium, Radium and Thorium isotopes are depleted (but enriched in the slag, where Pb 210 and Po 210 are depleted). Because Pb 210 and Po 210 are β- and α-emitters, respectively (there is only a very small γ-line at 46 keV from decay of Pb 210) no external dose by γ-radiation result from, but only a weak inhalation dose raised from the β-emitter Pb 210 and the α-emitter Po 210 while the dose effective α-emitters U 238, U 234, Th 230 and Ra 226 are missing.

These arguments lead to the following conclusions:

- In case of bulky transport of raw materials in radioactive equilibrium and a 50 % share of the inhalation dose to the total dose the 10fold exempt concentration (U_{nat} + Th_{nat}) leads to en exposure up to 0.5 mSv yr^{-1} for a working time of 500 hr.
- If assuming a maximum permissible dose of 0.3 mSv yr^{-1} to transport personnel (for comparison: the dose limit for a member of the public due to exposure to NORM is 1.0 mSv yr^{-1} in addition to the natural radiation exposure according to IAEA BSS /IAE 96/) the five fold exempt limit for NORM in radioactive equilibrium would meet these requirements. This value is independent from the kind of material because the external dose by γ-radiation is solely caused by short lived γ-emitting decay products of Ra 226 and Ra 228. Furthermore, all α-emitters of both decay chains contribute similarly to the inhalation dose in case of radioactive equilibrium. Small differences result only from the activity ratio between U_{nat} and Th_{nat}.
- In case of the transport of packaged material with radioactive equilibrium the dose to the personnel is solely caused by external exposure by γ-radiation. With the 10fold exempt limit a dose constraint of 0.3 mSv yr^{-1} would not exceeded, independent from the kind of material due to the same reason as mentioned before.
- In case of material with radioactive non-equilibrium the value of exempt activity concentration must be calculated by means of the formula in para. 405 of TS-R-1 /IAE 09/, because the application of the 10fold exempt concentration for each single natural radionuclide according to Table 2 in TS-R-1 is for physical reasons unjustifiable.

- As explained before, the application of the 10fold exempt limit of 95 Bq g^{-1} of Ra 226 (calculated after para. 405 of TS-R-1) would lead to a dose to personnel of about 2.0 mSv yr^{-1} for 500 working hours. Subsequently, the proposed dose limit of 0.3 mSv yr^{-1} would comply with a Ra 226 activity concentration of about 15 Bq g^{-1}. This value corresponds to a 1.5 fold exempt concentration for Ra 226 according to Table 2.1 of TS-R-1.

- For Ra 228 the maximum activity concentration is limited to 7 Bq g^{-1} (calculated after para. 405 of TS-R-1) due to the yielding equilibrium with Th 228 having a ten times lower exempt limit. Consequently, for Ra 228 already the basic exempt limit of 10 Bq g^{-1} is not achievable due to physical regularities, i.e. the maximum dose to transport personnel is in that case less than 0.1 mSv yr^{-1}.

- The peculiarity of material resulting from thermal processes such as filter dust and fly ash concerns the accumulation of the highly volatile natural radionuclides Pb 210 and Po 210, usually in secondary equilibrium. The 10fold exempt limit would be 100 Bq g^{-1} of each nuclide according to Table 2 of TS-R-1 but 50 Bq g^{-1} of each nuclide by means of the formula in para. 405 of TS-R-1. For such materials only the dose to personnel by inhalation of dust must be taken into account due to the absence of γ-emitting decay products. Because only both nuclides contribute to the internal dose (the most relevant α-emitters U238, U 234, Th 230, Ra 226 stay before these nuclides within the Uranium-Radium decay chain) the dose to transport personnel is less than 0.1 mSv yr^{-1} for a working time of 500 hours.

The following recommendations are given as far as the proposed dose limit of 0.3 mSv yr^{-1} for transport personnel is accepted:

1. For bulky transport of NORM with radioactive equilibrium the five-fold activity concentration for exempt material meet this requirement independent on the kind and use of such materials.

2. Accordingly, para. 106 (e) could be amended as follows:

– Delete the hint to the indented use (i.e. „… other than for the extraction of the radionuclides, and that are not intended to be processed for use of these radionuclides,…”).

- Furthermore, the last part of the sentence in para. 106 (e) with the hint to paras 401 (b) to 406 should be replaced by a new paragraph which contains the limits for natural radionuclides only, i.e.:
  - 5 Bq g^{-1} for both, U_{nat} and Th_{nat} in case of radioactive equilibrium;
  - in case of radioactive non-equilibrium the activity concentration for exempt material should be calculated by means of the formula in para. 405 of TS-R-1 with a limit of

    - 15 Bq g^{-1} for Ra 226 and of 10 Bq g^{-1} for Ra 228
  - the 10fold exempt limit of 100 Bq g^{-1} for Pb 210 and Po 210, each in non-equilibrium is thoroughly applicable regardless there limitation to 50 Bq g^{-1} of each by application of the formula in para. 405 of TS-R-1.

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