Exposure of Workers from the Transport of NORM in Germany

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Objectives (1)

GRS participated on the Coordinated Research Program (CRP) on Safe Transport of NORM of IAEA from 2007 to 2010

- **The CRP was related to updating of IAEA safety standard T-SR-1 with special emphasis on the transport of NORM**
- **The transport limits for exempt materials or consignments containing only natural occurring radionuclides were till now developed more or less randomly, and did not based on radioecological models compared to those regarding artificial radionuclides**

Objectives (2)

The following issues had to be evaluated on the radiological protection point of view:

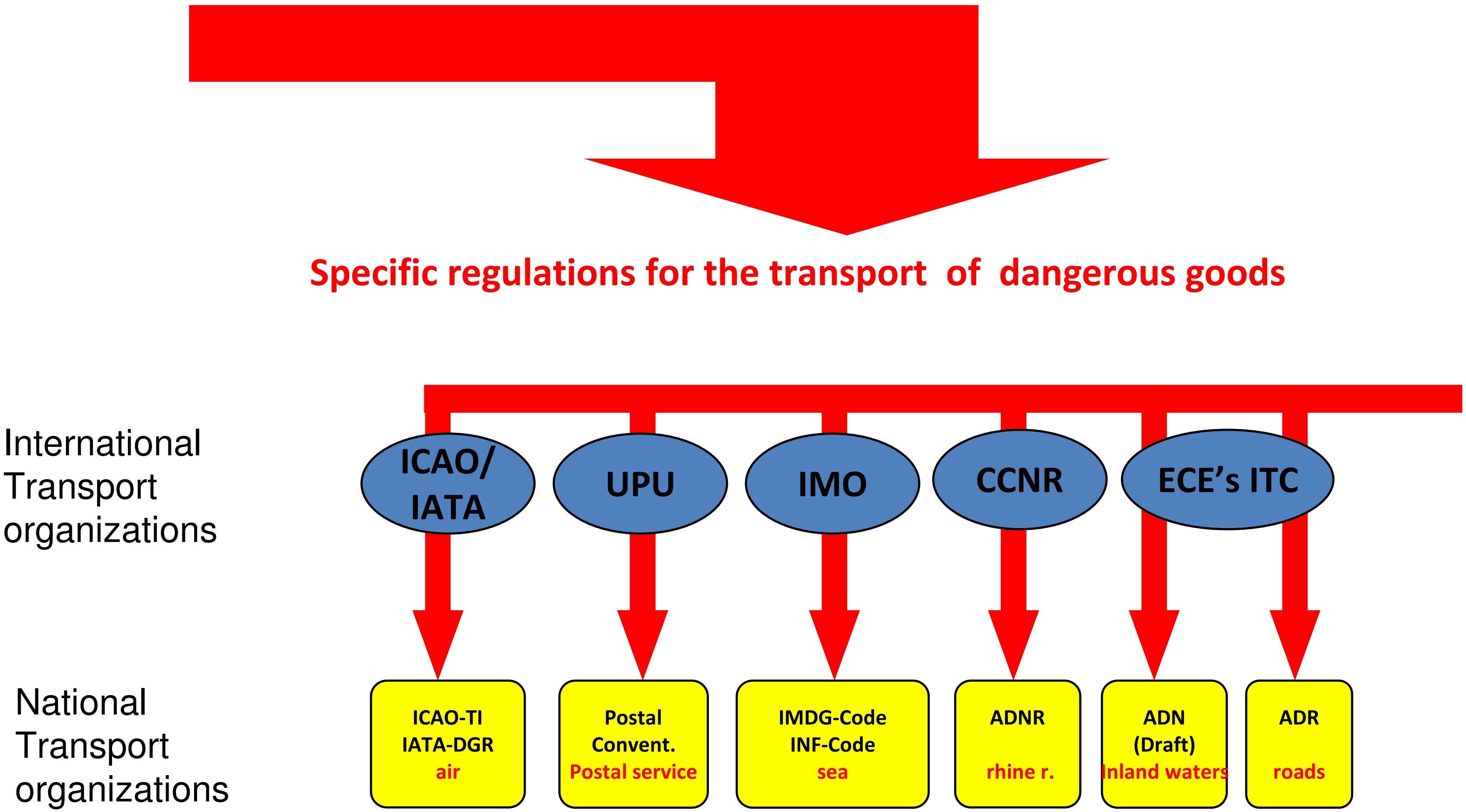
- **Is the general use of the 10fold nuclide specific exempt value according to Table II of T-SR-1 (para 402) satisfied independent on the state of physical equilibrium within the natural decay chains?**
- **Why the application of the 10fold exempt value is not applicable for the transport of uranium and/or thorium ore exploited for the use of its radioactivity (Para 409 a)?**
- **Is there an urgent need to apply the sum formula of Para 405 also for NORM in non-equilibrium?**
- **The transport exempt limits for artificial radionuclides are based on the de minimis concept of 10 μSv/yr. Regarding radiation BSS the limit of 1 mSv/yr is in general applied for NORM. Should this dose limit be also valid for the transport of NORM or should be a detriment of 0.3 mSv/yr applied?**

Objectives (3)

GRS services under the IAEA CRP on NORM

- **Overall status review and categorization of most relevant NORM in Germany**
- **Status review, analysis and evaluation of NORM shipments and expected radiation exposure of the shipment staff by NORM materials, 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 or consignments for transportation according to ADR/RID for NORM in non-equilibrium, the applicability of homogeneity criteria and relevance of associated conventional harmful substances**

Implementation of IAEA recommendations (1)



Implementation of IAEA recommendations (2)

IAEA.org
International Atomic Energy Agency

Нормы безопасности МАГАТЭ
для защиты людей и охраны окружающей среды

Правила безопасной перевозки радиоактивных материалов
Издание 2005 года

Требования безопасности
№ TS-R-1

IAEA
Международное агентство по атомной энергии

Recommendations
(Activities, Definitions, Packaging)

ST/SG/AC.10/1/Rev.14 (Vol.I)

Recommendations on the
TRANSPORT OF DANGEROUS GOODS

Model Regulations

Volume I

Fourteenth revised edition

UNITED NATIONS
New York and Geneva, 2005

Implementation of IAEA recommendations (3)

Principal legal basis for the status review and transport of NORM in Germany:

- **German Radiation Protection Ordinance (StrlSchV), § 97 with Annex XII and § 102**
- **IAEA TS-R-1 or Annex A of ADR, especially No. 2.2.7.1.2 e (non-equilibrium) and use of 10fold-value (No. 2.2.7.7.2.1 b)**
- **Annex XII Part A of StrlSchV contains only NORM residues (wastes), but no raw materials and by-products**
- **Raw materials and by-products which apply to the definition of NORM are considered in relation to their corresponding residues (Annex XII Part A of StrlSchV)**

Definition and description of scenarios (1)

Transport scenarios were defined for the following NORM

- **Tantalum raw materials (Microlyte, Tantalite, Columbite, Tin slag)**
- **Raw phosphate**
- **Pipe scales and 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 waterworks**

Definition and description of scenarios (2)

Exemption conditions for non equilibrium:

The derived A1 or A2 value or the limit of total activity / specific activity according to TS-R-1 para. 405 is :

$$X_m = \frac{1}{\sum_i \frac{f_i}{X_i}}$$

f(i) portion of activity /concentration of nuclide i in mixture
X(i) corresponding A1 or A2 – value or exempt value of nuclide i
X(m) derived value of A1 or A2 – value or exempt limit for „mixture“

Definition and description of scenarios (3)

Examples for calculation of exempt limits for natural gas scales

$$X_m = \frac{1}{\sum_i \frac{f_i}{X_i}}$$

based on measured data (EEG)		based on data of /KOL 85/	
f_{Ra226} = 0.33	13.5 Bq/g	f_{Ra226} = 0.49	46.1 Bq/g
f_{Pb210} = 0.19	7.8 Bq/g	f_{Pb210} = 0.25	23.5 Bq/g
f_{Po210} = 0.19	7.8 Bq/g	f_{Po210} = 0.25	23.5 Bq/g
f_{Ra228} = 0.13	5.3 Bq/g	f_{Ra228} = 0.005	0.5 Bq/g
f_{Th228} = 0.16	6.6 Bq/g	f_{Th228} = 0.007	0.7 Bq/g

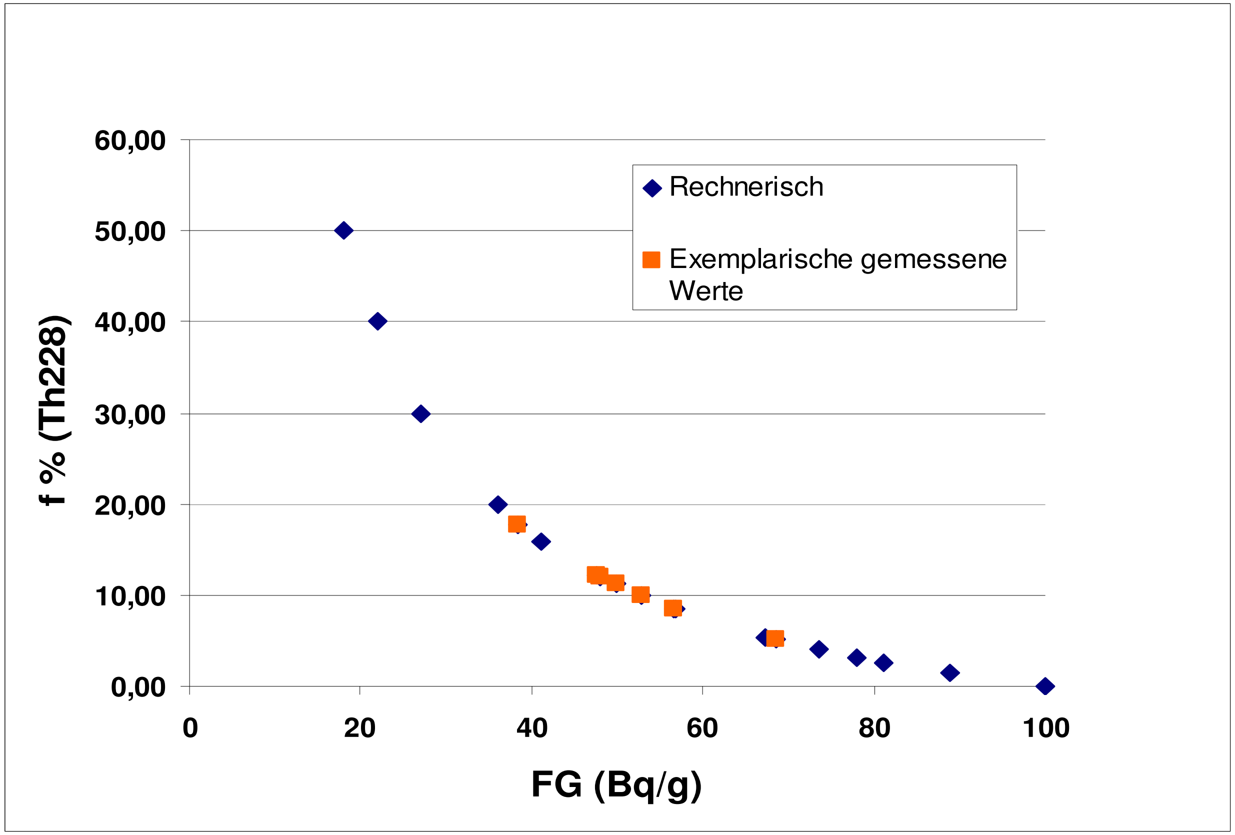
= 0.84/100 + 0.16/10 = 0.0244

1/0.0244 → **41.0**

= 0.995/100 + 0.007/10 = 0.01065

1/0.01065 → **93.9**

Definition and description of scenarios (4)



Min.: **16 Bq/g** (only Ra 228)   Max.: **100 Bq/g** (only Ra 226)

Definition and description of scenarios (5)

Parameters for the calculation of external exposure

According to /BFS 10/ the following parameters could be 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 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-equilibriu

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

The comparable conversion factor within the Thorium decay chain in radioacti 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 mc acres (e.g. waste rock piles). Measurements of gamma dose at contaminated materials 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-equilibriun

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)

Definition and description of scenarios (6)

Parameters for the calculation of internal exposure by inhalation of dust

According to /BFS 10/ the following parameters could be applied to specific transport scenarios:

$\dot{V}_j$: 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}

Definition and description of scenarios (7)

Inhalation dose coefficients $g_{Inh,r,j}$ for the radionuclide r as well as inhalation dose coefficients $g_{Inh,j}$ of the radionuclide mixture for the reference person "employee"

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 t ICRP Publication 71 (para. 58). For Ac pulmonary absorption class F is effective.

Definition and description of scenarios (8)

Gamma dose rate around small freight containers

Distance (m)	Ratio γ-DR in distance x [m] : γ-DR at surface				
	mean	S.D.	minimum	maximum	**Recomm.**
0.50	0.49	0.070	0.42	0.56	**0.55**
1.00	0.23	0.042	0.13	0.33	**0.30**
2.00	0.097	0.020	0.06	0.13	**0.15**
5.00	0.024	0.006	0.015	0.046	**0.05**
10.00	0.007	0.0015	0.0038	0.01	**0.01**

Bulk cargo of Tantalum raw materials (1)
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**

Values of specific activities used for dose calculation

Material	Specific activity [Bq/g]	
	U_{nat}	Th_{nat}
Microlyte	30	10
Tantalite	15	5
Columbite	15	5
Tin slag	3	1

Bulk cargo of Tantalum raw materials (2)

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

Bulk cargo of Tantalum raw materials (3)

Exposure of transport workers

Material	U_{nat} [Bq/kg]	Th_{nat} [Bq/kg]	Personnel	Hours worked per year	Dust, $H_{(Inh,j)}$ [mSv/yr]	Radon, $H_{(Inh,j)}$ [mSv/yr]	external, $H_{(E,j)}$ [mSv/yr]
Microlyte	30.000	10.000	Yard worker	500	9.80E-01	8.60E-03	1.05E+00
Tantalum Raw Materials	7.500	2.500		500	2.45E-01	2.15E-03	2.63E-01
Microlyte	30.000	10.000	Truck driver	250+100	1.96E-01	1.72E-03	4.59E-01
Tantalum Raw Materials	7.500	2.500		250+100	4.05E-02	3.44E-04	1.15E-01

Shipment of contaminated pipes in container

Scenario description (1)

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

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:

10 Bq/g Ra 226 (scales in tubes) ~ 190 nSv/h (container surface)
10 Bq/g Ra 228 (scales in tubes) ~ 300 nSv/h (container surface)

Shipment of contaminated pipes in container

Scenario description (2)

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}			

Shipment of contaminated pipes in container

Exposure of transport workers

Personnel	Hours worked per year	Shielding (steel), [cm]	Distance, [m]	External, $H_{(E,j)}$ [mSv/yr]
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**

Based on a total activity of long lived natural radionuclides of 440 Bq/g

Summary and conclusions (1)

- The transport scenarions included both, the drivers of vehicles and the staff dealing with loading and unloading
- The scenarios concerned bulky or unpackaged transport and packaged transport
- The dose by inhalation of dust must only be taken into account for bulky transport scenarions in addition to the external dose by γ-radiation
- Special attention was paid on calculation of exposure resulting from transport of materials with non-equilibrium of radionuclides of U-Ra-chain and Th-chain

Summary and conclusions (2)

- **The 10fold limit for exempt materials containing only natural radionuclides , e.g. 100 Bq/g for Radium isotopes, is only a theoratical value due to the need for derivation of this limit by means of the formula given in para. 405 of TS-R-1**

- **As the value for activity concentration of e.g. Th228 is by factor 10 lower than for Radium isotopes or Pb/Po210 the limit of activity concentration decisively depends on the share of Th228 (fTh_{228})**

- **The external dose by γ-radiation depends solely from the activity concentration of Ra226 and/or Ra228 independent on the equlibrium status because no γ-emitters appear before Ra226 and Ra228 in the decay chains**

Summary and conclusions (3)

- For all scenarios on transport of packaged materials only the external dose must be considered while the dose by dust inhalation is neglegible in that case
- Accordingly, the application of the 10fold value for U_{nat} and Th_{nat} is non-restrictive for transport of packaged material. The resulting external dose is less than about 0.3 mSv/yr, in most cases less than 0.1 mSv/yr
- Contrary, the application of the 10fold value for U_{nat} and Th_{nat} is restrictive for transport of unpackaged material due to the consideration of the dust inhalation path. A 5fold value for U_{nat} and Th_{nat} is proposed

Summary and conclusions (4)

- The activity concentration of Ra226 and Ra228 is linearly correlated to the external dose independent on the kind and indented use of the shipped material

- The application of the 10fold value for materials of radioactive non-equilibrium with a Ra226/Ra228 ratio $\geq$ 5 and subsequently a gross activity concentration of exempt material of > 75 Bq/g could cause a dose > 1 mSv/yr. Therefore the following limitation for the activity concentration of Ra isotopes of
  15 Bq g^{-1} for Ra 226 and 10 Bq g^{-1} for Ra 228
  is proposed
- 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.

What we realy achieved

- The application of the formula on mixed radionuclides in Para. 405 von TS-R-1 is now obligatory
- The application of the 10fold value of exempt material/consignment is valid for all kind of NORM indepondent of its further use
- The application of the dose limit of 0.3 mSv/yr instead of 10 μSv/yr as for artificial radionuclides was agreed