DERIVATION OF EXEMPTION AND CLEARANCE LEVELS FOR NORM

C. Timmermans[1], S. Thierfeldt[2], S. Mobbs[3], M-L. Perrin[4]
[1]NRG, P.O. Box 9035, NL-6800 ET Arnhem, The Netherlands
[2]Brenk Systemplanung GmBH, Heider-Hof-Weg 23, D-52080 Aachen, Germany
[3]NRPB, Chilton, Didcot, Oxon, OX11 0RQ, United Kingdom
[4]IPSN/DPHD/SEGR, BP 6, F-92265 Fontenay aux Roses Cedex, France

1 ABSTRACT

In Title VII of the Euratom Basic Safety Standards special attention is given to increased exposures to natural sources of radiation which cannot be disregarded from a radiological point of view. The concepts of exemption and clearance are also applied to these so called work activities, which involve handling of materials with enhanced levels of natural radioactivity but which are not processed because of their radioactive, fissile or fertile properties.The Article 31 Working Party on Exemption and Clearance of the European Commission has derived exemption and clearance levels for NORM which are, contrary to those derived for artificial radionuclides, based on a dose criterion of 0.3 mSv/a, which is within the variation of the natural background. For the derivation of the exemption and clearance levels a set of fourteen descriptive exposure scenario's are developed which for reasons of radiation protection are conservative, yet realistic. The scenario's comprise exposures of workers as well as member of the general public due to the transport, reuse, recycling and disposal of cleared NORM, and should be regarded as enveloping for all possible situations.
The resulting exemption and clearance levels are, for most types of NORM, within the range of 0.3 – 0.4 Bq/g for the two main natural series up to about 10 Bq/g for individual natural radionuclides.

2 INTRODUCTION

The concepts of exemption of practices and clearance of radioactive materials and sources from regulatory control have been introduced in the new Euratom Basic Safety Standards (1) for the protection of the health of workers and members of the general public against the dangers arising from ionising radiation (Council Directive 96/29/Euratom of 13 May 1996). According to ICRP publication 60 (2) the concepts of exemption (and clearance) are based on two grounds. The first one is the triviality of dose from a given exempted source, the second is that no reasonable control procedures can achieve significant reductions in individual and collective doses. These concepts relate to the regulatory control of practices. They can however also be applied to work activities, i.e. the processing of materials involving the presence of natural radiation sources which can lead to a significant increase in the exposure of workers or members of the public that cannot be disregarded from the radiation protection point of view.

The question is then which dose can be regarded as trivial compared to normal background doses which are also related to natural radioactivity in the soil, building materials, foodstuffs etc. For practices a trivial dose is assumed to be in the order of a few tens of microsieverts (3). For practical reasons a dose criterion of 10 μSv per year is used, allowing for multiple exposures to different sources of radiation. Applying such a low dose criterion to NORM will however result in activity concentrations which are at the lower end of the existing natural activity concentrations, bringing large areas of the Earth under regulatory control. The Art. 31 Working Party on Exemption and Clearance therefore decided that a dose criterion for NORM should be in the range of the variability of the natural background dose within the member states, i.e. between 0.1 and 1 mSv per year. A value of 0.3 mSv in addition to the natural background, for workers as well as members of the public was regarded as sufficiently low (4). Moreover, contrary to practices, multiple exposures to different sources are hardly possible regarding the very large volumes of NORM which are produced annually.

Since the dose criterion is additional to the background dose, the question which then arises is how to distinguish between the normal levels of natural radioactivity in a material and the enhanced radioactivity since both occur from the same radionuclides. This problem is bypassed by adding to the dose criterion that part of the background dose which is saved by the application of the cleared NORM. In this case the calculated exemption/clearance levels already include the normal levels of radioactivity in the material. Measurement of the radioactivity to comply to the exemption/clearance levels is then for the total activity of a certain radionuclide in the material.

The radionuclides for which exemption and clearance values are calculated are listed in table 1. Only natural radionuclides belonging to the thorium and uranium-238 and 235 series with a sufficient long half live, as well as ^{40}K are taken into account. The table also shows the radionuclides which are considered to be in secular equilibrium with the parent nuclide. The contributions of the daughter nuclides are incorporated in the dose coefficients of the parent nuclide according to their radiological properties. For these short lived radionuclides no separate levels are derived.
It should be noted that the calculations for the ^{238}U series in secular equilibrium and ^{238}U also include the contributions of the isotopes ^{234}U and ^{235}U, which occur in nature in an activity ratio of 100% respectively 4.6% relative to the ^{238}U activity.

The types of NORM which are eligible for clearance can be quite divers. In order to restrict the number of calculations they are grouped in five general classes: rock, sand, ash and slag type materials and (wet) sludge's of the oil and gas industry. For each of these types of material assumptions are made of the annually generated amounts, the applicability of the material considering a certain use, the dispersability and the leachabillity. The choice of different parameters for different materials may lead to material specific exemption and clearance levels.

Table 1: Natural radionuclides for which exemption/clearance values are calculated

Parent nuclide	Nuclides considered in secular equilibrium
^{235}U series	^{235}U, ^{231}Th, ^{231}Pa, ^{227}Ac, ^{227Th} (98.6%), ^{223}Fr (1.4%), ^{223}Ra, ^{219}Rn, ^{215}Po, ^{211}Pb, ^{211}Bi, ^{207}Tl (99,7%), ^{211}Po (0,3%)
^{235}U	^{235}U, ^{231}Th
^{231}Pa	^{231}Pa
^{227}Ac	^{227}Ac, ^{227}Th (98.6%), ^{223}Fr (1.4%), ^{223}Ra, ^{219}Rn, ^{215}Po, ^{211}Pb, ^{211}Bi, ^{207}Tl (99,7%), ^{211}Po (0,3%)
^{238}U series	^{238}U, ^{234}Th, ^{234m}Pa, ^{234}Pa (0.2%), ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po + ^{235}U series (4.6%)
^{238}U	^{238}U, ^{234}Th, ^{234m}Pa, ^{234}Pa (0.2%), ^{234}U + ^{235}U (4.6%)
^{230}Th	^{230}Th
^{226}Ra	^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po
^{210}Pb	^{210}Pb, ^{210}Bi
^{210}Po	^{210}Po
^{232}Th series	^{232}Th, ^{228}Ra, ^{228}Ac, ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po (64.1%), ^{208}Tl (35,9%)
^{232}Th	^{232}Th
^{228}Ra	^{228}Ra, ^{228}Ac
^{228}Th	^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po (64.1%), ^{208}Tl (35,9%)
^{40}K	^{40}K

The sequence of the calculations is the following:

1. choice of enveloping scenarios
2. determination of exposure pathways
3. choice of parameter values based upon expert judgement
4. calculation of individual doses per unit activity concentration
5. calculation of the activity concentration corresponding to the dose criterion
6. identification of the limiting values, scenarios and pathways

3 ENVELOPING SCENARIOS

In order to determine the most restrictive values for the exemption/clearance levels a number of scenarios was developed, each of which is assumed to be enveloping for a particular fate of the cleared NORM. The main scenarios that can be distinguished after the material is cleared are the following:

- intermediate storage with or without processing of the material
- reuse of the material as building material
- disposal of the material.

Each of these scenarios involves preceding transport of the cleared NORM from the authorised work activity to the next phase.

In figure 1 an outline is given of the main clearance routes for NORM.

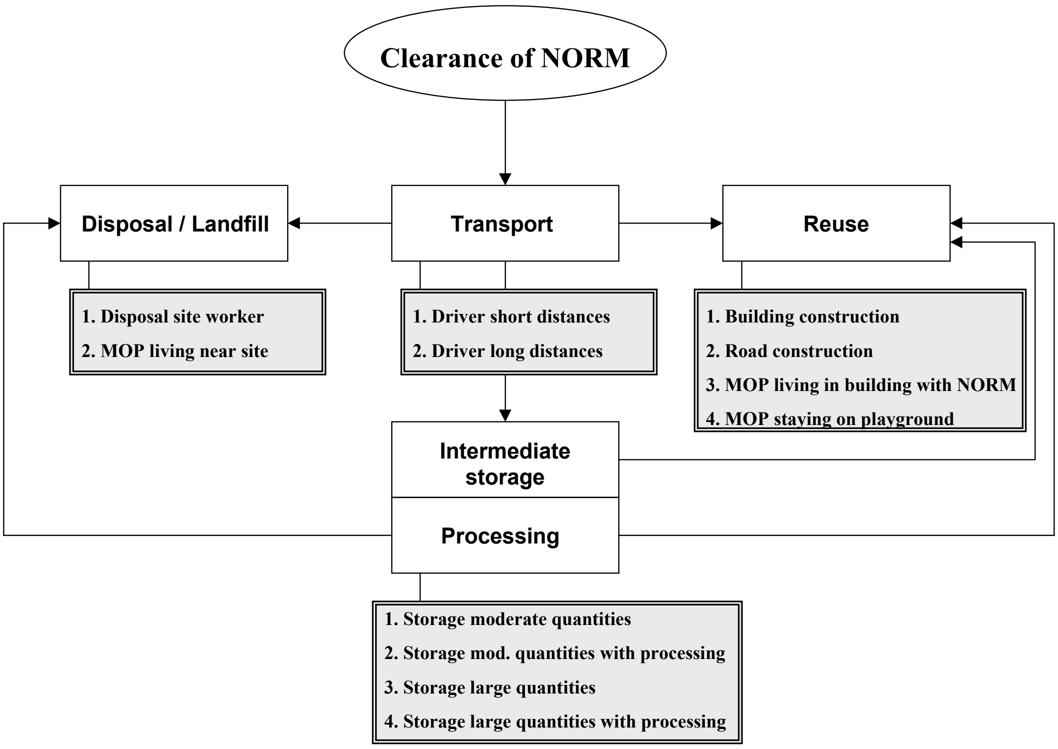

Fig. 1: Routes and scenarios for the calculation of clearance levels for NORM

The transport scenario is subdivided in a scenario which describes transport over short distances and a scenario for transports over long distances. For each scenario it is assumed that the truck drives back empty or is loaded with non-radioactive material.

The next scenario which is considered is (intermediate) storage of the cleared NORM. The scenarios are storage of moderate quantities indoors and storage of large quantities which, for obvious reasons, only occurs outdoors. The storage scenarios are calculated with and without processing of the materials.

Disposal on a landfill or heap will generally occur without intermediate storage, except when the material has to be pre-processed before it can be disposed of. This is for instance the case for wet sludge's of the oil and gas industry, which

often contain organic material and toxic chemical substances, which prevent it from direct disposal but also from reuse in f.i. building materials.
Many NORM materials are very suitable for reuse, especially as a building material. Sometimes the cleared materials can be reused directly, but in most cases they will need some processing (with intermediate storage at the site where it is processed) to make it suitable for further reuse.

4 EXPOSURE PATHWAYS AND PARAMETERS

The exposure scenarios are chosen to be descriptive, which means that for each scenario all possible exposure pathways are considered and the doses are added. The relevant exposure pathways are direct external irradiation, inhalation of dust, direct ingestion of deposited dust and indirect ingestion of radioactivity via contaminated foodstuffs.
For the external pathways nuclide specific dose rates for unit activity concentration are calculated considering the scenario specific geometry's of the sources and exposed persons.
The inhalation pathways are calculated taking into account the most restrictive dose coefficients for inhalation given in the annex of the BSS, a breathing rate of 1.2 m^3/h and scenario specific dust concentrations and exposure times. Arising dust concentrations are assumed to depend on the type of material.
The direct ingestion pathways are calculated assuming a fixed ingestion rate of 10 mg/h of exposure during working conditions, with age specific values for members of the general public for the appropriate scenarios. Indirect ingestion of radioactivity via contaminated foodstuffs occurs in only one scenario:.

Table 2: Scenario specific parameters

Scenario	Internal pathways		External pathway		
	exp. time (h)	dust concentr. (mg/m^3)	exp. time (h)	source size (ton)	dist. (m)
Transport short distances	400	1	700	30	1
Transport long distances	100	1	850	30	1
Storage moderate quantities, indoors	1800	0.5 – 1	1800	1500	5
Storage moderate quantities with processing	1800	2	1800	1500	5
Storage large quantities, outdoors	1800	0.2 - 0.5	1800	15,000	10
Storage large quantities with processing	1800	1	1800	15,000	10
Disposal in landfill or heap	1800	1	1800	1,500,000	1
Road construction	1800	1	1800	800	1
Building construction)*	1800	0.5	1800	20	1.5
Building construction with undiluted material	1800	0.5	1800	0.9	1
Unfixed surface layers / sports grounds	500	0.5	500	2000	1
House near landfill or heap	7000	0.02 -0.5	7000	1,500,000	1 - 25
House build with NORM added materials)*			7000	20	1.5
House build with undiluted NORM			7000	0.9	1.5

)* assuming 30% dilution for rock, sand and slag, and 10% for ash

Members of the general public living next to a landfill or heap where NORM is disposed of. In this scenario home grown vegetables are assumed to get contaminated by direct deposition of dust, and via irrigation with contaminated ground water from a private well

The latter pathway involves modelling of groundwater transport, deposition on leafy vegetables as well as root uptake. Indirect ingestion via drinking water from a private well is considered to be a less realistic assumption for most EU member states. For public drinking water supplies the drinking water directive (5) of the EC applies.

In table 2 some scenario specific parameters are given for the internal pathways inhalation and direct ingestion and the external pathway.

5 RESULTS

Table 3 presents for the different scenarios and types of material the calculated doses for unit activity concentration in the cleared material. The calculated doses are in the range of less than 1 µSv per year up to about 1 mSv per year. The limiting scenario is for gamma ray emitting radionuclides 'Living in a house build with NORM added building materials'. For the other radionuclides either the scenario 'Residence near a heap', due to the groundwater pathway, or 'Indoor storage of moderate quantities with processing', due to the inhalation of dust, is limiting.

As is explained in the introduction the dose criterion of 0.3 mSv per year is additional to the background dose. The normal background dose one is exposed to partially originates from the undisturbed soil or from natural building materials. When cleared NORM is applied, in some cases all or part of the background dose is reduced. For instance a landfill or heap shields the radiation of the underlying soil. Replacement of natural building materials with NORM reduces the background dose contribution of that material with the fraction of the material which is replaced. In fact this dose reduction can be added to the dose criterion of 0.3 mSv since it yields the same total dose (background dose plus dose criterion) as is intended for the clearance of NORM.

For the calculation of the reduction of the background dose the same scenarios are used with the average activity concentration in soil (6) and natural building materials (7) as input. The expanded dose criterion is then calculated as the sum of the individual dose criterion of 0.3 mSv per year and the averted background dose.

Table 4 gives the derived exemption and clearance levels based on the expanded dose criterion. The table presents the most restrictive values for all materials (rock, sand, slag and ash type materials) and separate values for sludge's from oil and gas production. Unrounded values as well as the recommended values rounded to 0.5, 1, 5 etc. are given.

From table 4 it can be seen that except for sludge's the differences between the different types of material are small and will in most cases not lead to another (higher) value when rounded. Therefore the recommended list of values is applicable to general clearance for all sorts of NORM residues. Where applicable the set of higher values for small amounts of sludge type residues can be used.

Table 3: Calculated doses (μSv/a) per Bq/g of specified radionuclides for different scenarios and types of material.

Scenario	Material	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po	^{232}Th	^{228}Ra	^{228}Th	^{40}K
Transport short distances	All	2	1	73	0.8	1.5	1.7	39	78	7
	Sludge	0.1	0	5	0	0	0	3	6	0.5
Transport long distances	All	7	4	86	3	6	7	48	103	8
	Sludge	0.1	0	6	0	0	0	3	6	0.6
Storage moderate quantities, indoors	Ash, sand	30	19	66	15	26	30	46	133	5
	Sludge	0.6	0	42	0	0	0	22	42	4
Storage moderate quantities with processing	All	58	35	71	18	31	56	50	207	5
	Sludge	4	1.9	43	1.5	3	3	24	49	4
Storage large quantities, outdoors	Ash, sand	16	12	64	14	24	17	44	96	5
Storage large quantities with processing	All	30	19	66	15	26	30	46	133	5
Disposal in landfill or heap	All	35	19	388	15	26	30	220	432	34
	Sludge	0.4	0.2	4	0.2	0.3	0.3	2	4	0.3
Road construction	Rock, slag	37	19	552	15	26	30	303	617	52
Building construction	Ro, Sa, Sl	8	3	248	4	7	5	137	242	23
Building construction with undiluted material	Ash	17	12	59	14	24	17	43	84	4
Unfixed surface layers / sports grounds	Ro, Sa, Sl	7	4	169	19	45	6	120	155	14
House near landfill or heap	Rock	11	11	232	75	102	99	292	216	17
	Sludge	0.2	0.1	2	0.8	1	1	3	2	0.2
House build with NORM added materials	Ro, Sa, Sl	13	0	957	0.2	0	0	516	896	102
House build with undiluted NORM	Ash	4	0	198	0.2	0	0	110	172	17

Table 4: Derived exemption and clearance levels for NORM (Bq/g).

Nuclide	All materials		Wet sludge's	
	Unrounded	Rounded	Unrounded	Rounded
^{235}U sec	0.73	1	9.2	10
^{235}U +	6.5 – 7.4	5	69	50
^{231}Pa	3.4	5	54	50
^{227}Ac +	1.0	1	13	10
^{238}U sec	0.43 – 0.68	0.5	5.6	5
^{238}U +	5.2	5	8.5	10
^{230}Th	8.6	10	150	100
^{226}Ra +	0.44 – 0.87	0.5	7	5
^{210}Pb +	4.0 – 17	5	200	100
^{210}Po	3.0 – 9.6	5	110	100
^{232}Th sec	0.30 – 0.49	0.5	3.9	5
^{232}Th	3.1 – 5.4	5	100	100
^{228}Ra +	0.82 – 1.5	1	12	10
^{228}Th +	0.47 – 0.78	0.5	6.1	5
^{40}K	4.2 – 9.9	5	78	100

6 REFERENCES

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