Application of Transport Regulations to NORM: Practical Guide

by

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Abstract

This paper provides an update on the issues associated with the transport of naturally occurring radioactive materials (NORM) in the mining and mineral processing industry and is an update of the earlier publication on the same topic, prepared by two of the authors from the original 2007 paper[1]. The update is required due to regulatory changes and several identified inaccuracies in the earlier publication.

The arguments in the 2007 publication were based on the 2005 IAEA Regulations for the Safe Transport of Radioactive Material [2] and the 2002 Advisory Material for the Regulations [3].

In the interim, both the International Regulations and the Advisory Material were re-issued several times [4–9], with documents [6] and [9] being currently applicable. Also, since the time of publication of the previous version of this paper, the regulations in Australia have also changed three times [10–13], with document [13] being currently applicable.

A preliminary assessment of the applicability of the current Transport Safety Regulations [6,9] to NORM was carried out by Calytrix Consulting in 2016-2019 and an informal technical reference note was published online in August 2019, together with the calculator created in MS Excel [14].

1. INTRODUCTION AND GENERAL CONSIDERATIONS

In many cases there is an insufficient level of communication in regards to the legal requirements between the supplier/exporter and consumer/importer of a mineral concentrate containing naturally occurring radioactive materials (NORM) and the relevant Regulatory Authorities. The lack of communication between logistics companies and government departments in different countries (and between the States within one country), combined with frequent misinterpretations of different legislative acts, regulations and guidelines very often results in serious challenges, both for the regulators and for the minerals industry.

The issue becomes much more complex if we consider the fact that International Transport Safety Regulations [6] are not adopted simultaneously across the world, and different requirements may apply in different jurisdictions.

It is essential that any mining and mineral processing company, and relevant logistics operators carefully examine all applicable legislation, to fully understand how radioactive material is defined within the respective jurisdictions where NORM is proposed to be transported, so as to be absolutely clear about which controls will apply to a specific material. It is also advisable that discussions are held with the local regulator to ensure a common understanding of interpretations and requirements.

The Definition of naturally occurring radioactive material (NORM) is given in the IAEA Safety Glossary [15] as follows:

Radioactive material containing no significant amounts of radionuclides other than naturally occurring radionuclides.

- *The exact definition of 'significant amounts' would be a regulatory decision.*
- *Material in which the activity concentrations of the naturally occurring radionuclides have been changed by a process is included in naturally occurring radioactive material (NORM).*
- *Naturally occurring radioactive material or*

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NORM should be used in the singular unless reference is explicitly being made to various materials.

There are 24 industries (listed in Table 1) where the management of NORM may be required. The situations where at least some items or materials may require an assessment of the applicability of transport safety regulations are highlighted in **bold blue font.**

1.2. Different modes of transport and types of packaging

In the consideration of the radiation safety measures to be applied to the transport of NORM the mode of transport is as important as its activity concentrations, in some cases even more important, as illustrated by an example below.

If NORM is packed in appropriate bags and placed inside containers, at the point of origin the only radiation exposure workers would receive will be from gamma radiation. There is, however, a significant concern for workers who would be opening the containers at their destination; the concentrations of radon (^{222}Rn) inside containers could be extremely high (in order of 10,000 Bq/ m^3) and the containers may need to stay opened for several hours, to allow for the reduction of radon concentrations through natural ventilation. This applies to the transport of any mineral concentrate containing uranium, irrelevant of the applicability of the Regulations, and to the transport of contaminated equipment from oil and gas, titanium pigment, geothermal energy generation, and other relevant industries.

If, however, NORM is transported in bulk, at the point of origin the dose for workers from dust and radon inhalation also needs to be considered, and in case of a marine shipment, where the same considerations for radon (as in the paragraph above) will apply to opening a ship's hull at a destination port.

Table 1. The list of NORM

Bauxite/aluminium	**Phosphoric acid production**
Building industry	**Titanium pigment**
Cement, clinker ovens	**Thermal phosphorus**
Coal-fired power plants	**Rare earths**
Geothermal energy	**Scrap metal recycling**
Hydraulic fracturing	**Tantalum**
Iron and steel	**Thorium compounds/products**
Mining ores other than uranium	**Tin, copper**
Niobium, ferro-niobium	Tunnelling
Oil and gas production	Water treatment
Paper and pulp production	**Zinc, lead**
Phosphate fertilisers	**Zircon and zirconia**

1.1. Material on a mining/processing site

The first step is to establish if the Regulations [6, 13] apply to the movement of potentially radioactive material. If the transport is within the boundaries of an authorised mining/processing site, the Regulations are not applicable, in accordance with §107(b):

107. The Regulations do not apply to:

…

- *(b) Radioactive material moved within an establishment that is subject to appropriate safety regulations in force in the establishment and where the movement does not involve public roads or railways.*

Despite the fact that such shipment does not need to comply with the Regulations, good radiological practice should nonetheless be followed during the transport on the authorised site.

If, however, there is a need to use a public road, railway or waterway, the requirements of the Regulations must be complied with.

1.3. Differences between ‘natural uranium’ and U (natural)

These two terms are not equal and, in many cases, the differences may need to be taken into account.

§247 of the Regulations [6] defines “natural uranium” as follows:

Natural uranium shall mean uranium (which may be chemically separated) containing the naturally occurring distribution of uranium isotopes (approximately 99.28% uranium-238 and 0.72% uranium-235, by mass).

This definition describes “chemically-separated uranium”, which means that the uranium decay chain may be disrupted, but the uranium nuclide mixture (^{238}U to ^{235}U ratio) is undisturbed (the uranium is not enriched in the ^{235}U isotope).

“**U(natural)**” is not the same as “natural uranium”. Whilst “natural uranium” refers to the non-enriched but possibly chemically separated uranium, “U(nat)” refers to chemically undisturbed uranium in secular equilibrium with its decay products.

Therefore, in almost all cases of NORM transport the material which has not been subjected to any chemical or thermal processing may be considered as “U(nat)”. Additional information on this issue is presented in [16].

This same argument applies to thorium ores, which have not been chemically- or thermally-processed and are classified as Th(nat).

1.4. Expected removal of U (natural) and Th(natural) concepts from the Regulations

It should be noted that the concept of U(nat) and Th(nat) has been removed in the latest edition of the International Basic Safety Standards (BSS) [17]. It is possible that the definitions and corresponding limiting values for U(nat) and Th(nat) will be removed from the subsequent edition of the International Transport Regulations as well, as they need to be aligned with the IAEA BSS.

It is not yet known which approach will be taken in the future in regards to the limits for natural radionuclides. Table I.1 of the BSS [17] contains the values for ^{232}Th and ^{238}U, but these exemption levels are:

(a) For “moderate amounts of materials”, the footnote to the Table I.1 clearly states, *the calculated values apply to practices involving small scale usage of activity where the quantities involved are at the most of the order of a tonne*. Therefore, these values cannot apply to the shipments of materials in mining and mineral processing industry, due to the fact that those always exceed the amount of one tonne.

(b) For ^{232}Th do not include any of the decay products (all of them are included in the case for Th(nat)), for ^{238}U only include two immediate decay products, not all of them, as is the case for U(nat).

Table I.2 of the IAEA BSS [17] is irrelevant for mining and mineral processing industry, as it addresses only artificial radionuclides.

The only relevant Table in the BSS [17] is I.3, which is *Levels for clearance of material: activity concentrations of radionuclides of natural origin*, which contains a single value, 1 Bq/g for *each radionuclide in the uranium decay chain or the thorium decay chain*.

If the same “10-times” exemption from the application of Transport Regulations applicable to NORM, described in section 2.1 below is maintained, nothing is expected to change for shipments of materials where ^{238}U and ^{232}Th decay chain radionuclides are in the state of secular equilibrium.

The Transport Safety Standards Committee of the IAEA is currently looking into this matter and will advise in due course.

2. CORRECT APPROACH TO THE TRANSPORT OF NORM AND CALCULATIONS

2.1. Definitions, determination of activity concentration and exemptions

If it is established that compliance with Regulations may be necessary, the next step is to determine the activity concentration of the material to be transported and compare it with the appropriate limits.

The Regulations[6] in Table 2, Basic Radionuclide Values specifies the values for Th (nat) and U (nat) at 1.0 Bq/g each.

The exemption for NORM is provided in §107(f) of the IAEA Regulations:

107. The Regulations do not apply to:
(f) Natural material and ores containing naturally occurring radionuclides, which may have been processed, provided the activity concentration of the material does not exceed 10 times the values specified in Table 2, or calculated in accordance with paras 403(a) and 404–407. For natural materials and ores containing naturally occurring radionuclides that are not in secular equilibrium the calculation of the activity concentration shall be performed in accordance with para. 405.

It is important to note that the ’10-times’ factor applies only to the activity concentrations, not to the ‘total activity of the consignment’.

The justification for the factor of 10 is provided in §107.4 of the Advisory Material [9],

A factor of 10 times the exemption value for activity concentration was chosen as providing an appropriate balance between the radiation protection concerns and the practical inconvenience of regulating large quantities of material with low activity concentrations of naturally occurring radionuclides.

Therefore, the actual limits for the minerals and associated products are raised to 10 Bq/g for Th (nat) and U (nat). Please note that the value of 10 Bq/g refers to the aggregate activity concentration of ^{232}Th and ^{238}U in equilibrium with their decay products, not to each element separately.

If the aggregate activity of U(nat) and Th(nat) in the material to be transported exceeds 10 Bq/g, there is still one more factor that needs to be considered, the Activity limit for an exempt consignment. These values are also provided in Table 2 of the Regulations [6].

In accordance with §236 of the Regulations,

Radioactive material shall mean any material containing radionuclides where both the activity concentration and the total activity in the consignment exceed the values specified in paras 402–407.

The total activity will always be exceeded in case of transport of tens of tonnes of minerals; however, this may not be the case when small packages are transported to and from laboratories.

For example, if a mineral concentrate containing 15 Bq/g of Th(nat) is to be transported, two limits will apply to its shipment:

- Activity concentration limit for exempt material, 10 Bq/g for Th(nat), and
- Activity limit for an exempt consignment, 1,000 Bq for natural thorium (the 10-times exemption factor for natural materials does not apply to the total activity limits).

The first limit is clearly exceeded (15 Bq/g > 10 Bq/g), but if the total mass of the package is less than 66 grams – the shipment will not fall under the provisions of transport safety regulations and will not need to be signposted or labelled.

The above consideration is particularly important for transporting small mineral samples to and from analytical laboratories.

2.2. Two different types of materials requiring different calculation methods

Radionuclides in ^{238}U and ^{232}Th decay chains in the material may or may not be in the state of secular equilibrium. “Secular equilibrium” means that the thorium and uranium decay chains in NORM have not been disturbed, no chemical or thermal processing took place. This applies to materials such as zircon and ilmenite sand, rare earth, tin and tantalum concentrates, where only physical processing (gravimetric, magnetic, etc) was carried out.

The complete data on the disruption of the secular equilibrium during processing is typically not available for many mineral products, but it is prudent to assume that this disruption may occur in cases of:

- Any chemical processing of the material, such as leaching or adding flotation agents to the process;

- Any thermal processing of the material. Due to the variety of different materials and methods used in their treatment it is impossible to establish a universal ‘cut-off’ point for the temperature, at which some radionuclides can volatilise and disrupt the equilibrium; the value of 250-300oC is suggested as a general guide at which additional analysis of the material may be required.

2.3. Transport of NORM in secular equilibrium

If thorium and uranium decay chains in a specific NORM are in equilibrium, both ^{232}Th and ^{238}U have much longer half-lives than any other nuclide in the respective decay chains; therefore, only Th(nat) and U(nat) concentrations (usually available in parts per million, ppm) are used in the calculations:

$$C(^{Bq}/_{g}) = \frac{Th\ (ppm) \times 4.055 + U\ (ppm) \times 12.859}{1000}$$

The factor for U(nat) of 12.859 takes into account the contributions from both U-238 and U-235.

If the result is less than 10, the material is exempt from Transport Safety Regulations [6].

It is important to note that the laboratories typically provide the values for the concentrations of uranium and thorium in the form of oxides, ThO_2 and U_3O_8. In this case the following coefficients must be used for the correct application of the equation above:

- 1 ppm of ThO2 equals to 0.879 ppm of Th,
- 1 ppm of U3O8 equals to 0.848 ppm of U.

Practical example 1

Mineral concentrate in secular equilibrium contains 250 ppm ThO_2 and 40 ppm of U_3O_8.

- Th(nat) = 250 x 0.879 = 220 ppm, U(nat) = 40 x 0.848 = 34 ppm,
- Activity concentration = (220 x 4.055 + 34 x 12.589)/1000 = 1.33 Bq/g,
- 1.33 Bq/g < 10 Bq/g, this mineral concentrate is exempt from Transport Safety Regulations [6].

2.4. Transport of NORM containing “non-series” radionuclides

In some circumstances the concentrations of the radionuclides that are not part of ^{232}Th, ^{238}U and ^{235}U decay chains may also need to be considered. The following applies to the transport of spodumene/lithium concentrates and products containing significant concentrations of potassium such as fertilisers or fruit juice concentrates.

These materials typically contain uranium and thorium in concentrations of less that 0.1 Bq/g, therefore these can be disregarded. However, the concentrations of the naturally occurring radionuclides such as ^{40}K and ^{87}Rb may be relatively high and needs to be considered before transport of some materials.

The limiting concentrations in the Regulations [6] are as follows:

- ^{40}K – 100 Bq/g (1,000 Bq/g for NORM), and
- ^{87}Rb – 10,000 Bq/g (100,000 Bq/g for NORM).

As in case of uranium and thorium, the laboratories typically provide the results for the oxides, K_2O and Rb_2O and there is also a need to consider that only a fracton of total potassium and rubidium are radioactive isotopes.

The following coefficients must be used to convert the concentrations of oxides to concentrations of metals:

- 1 ppm of K_2O equals to 0.830 ppm of K
- 1 ppm of Rb_2O equals to 0.914 ppm of Rb

The specific activity of ^{40}K is 265,267 Bq/kg, but as only 0.012% of potassium is ^{40}K, when converted from K(ppm) value the value is 32 Bq/kg.

The specific activity of ^{87}Rb is 3,099 Bq/kg, but only 28% of rubidium is ^{87}Rb, therefore, when converted from Rb(ppm) value is 868 Bq/kg.

It is important to note that it is extremely unlikely that NORM containing only potassium and rubidium will ever be a subject to the Transport Safety Regulations and the data is provided for information only, for very rare cases when ^{40}K and ^{87}Rb may need to be considered in the fractions equation (part 2.6 below), alongside radionuclides from thorium and uranium decay chains.

Practical example 2

Mineral concentrate in secular equilibrium contains 7% of K_2O and 0.5% of Rb_2O.

- K = 70,000 x 0.830 = 58,100 ppm, Rb = 5,000 x 0.914 = 4,570 ppm,
- ^{40}K activity concentration = 58,100 x 0.032/1000 = 1.86 Bq/g
- ^{87}Rb activity concentration = 4,570 x 0.868/1000 = 4.00 Bq/g,
- The values are significantly less than the transport limits (1,000 Bq/g for ^{40}K and 100,000 for ^{87}Rb) and it is clear that this mineral concentrate is exempt from Transport Safety Regulations.

2.5. Transport of NORM not in secular equilibrium, general considerations

As noted in part 2.2 above, for many materials and mineral concentrates the analysis of only uranium and thorium is not sufficient.

Correction Note 1: The calculations for the materials where the radionuclides in thorium and uranium decay chains are not in secular equilibrium were incorrect in the previous version of this paper [1]. It was previously assumed that the concentrations of all radionuclides (even very short-lived ones) need to be considered.

However, in accordance with §404 of Transport Safety Regulations [6], this is not correct:

In the calculations… a single radioactive decay chain in which the radionuclides are present in their naturally occurring proportions, and in which no daughter nuclide has a half-life either longer than 10 days or longer than that of the parent nuclide, shall be considered as a single radionuclide.

In the case of radioactive decay chains in which any daughter nuclide has a half-life either longer than 10 days or longer than that of the parent nuclide, the parent and such daughter nuclides shall be considered as mixtures of different nuclides.

Correction Note 2: The ‘mixtures’ equation from the §405 of the Regulations [6] applies to the materials where the decay chains are not in secular equilibrium. §I.81 in Advisory Material to the Regulations [9] repeats this equation, but §I.80 in [9] contains the old calculation method (“ratio”), which is much simpler to use. It should be noted that the same results are achieved when using one or another method of the calculation.

The following steps are suggested for the accurate estimation of the applicability of the Regulations [6] to the transport of NORM, where it is suspected that secular equilibrium between radionuclides in ^{238}U and/or ^{232}Th decay chains may have been disrupted by processing.

A. If both the producer/transporter and the regulatory authority agree that ^{238}U and ^{232}Th are in equilibrium, the analysis is to be performed only for U and Th.

B. If it is suspected that one or both of the decay chains may be in disequilibrium, the analysis is performed only for the limited set of radionuclides, after the consultation with the regulator:

- ^{232}Th decay chain: ^{232}Th, ^{228}Ra, ^{228}Th;
- ^{238}U decay chain: ^{238}U, ^{234}U (no analysis needed, assumed to be equal to ^{238}U), ^{230}Th, ^{226}Ra, ^{210}Pb;
- ^{235}U decay chain: Usually not required.
- If it is confirmed that both ^{232}Th and ^{238}U decay chains are in equilibrium – return to step A for all subsequent analyses (part 2.3 above, just U(nat) and Th(nat));
- If the disequilibrium is confirmed – proceed to step C.

C. Analyse for the following radionuclides to determine the applicability of Regulations [6] to the specific material (full set):

- ^{232}Th decay chain: ^{232}Th, ^{228}Ra, ^{228}Th;
- ^{238}U decay chain: ^{238}U, ^{234}Th, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po;
- ^{235}U decay chain: only if required by a customer/transporter or requested by the Regulatory Authority: ^{235}U, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Ra.

The footnote (b) to the Table 2 of the Regulations [6] states that the concentration of one isotope may be considered to include the concentrations of its decay products. For example, this footnote states that ^{226}Ra may “cover” the remainder of the ^{238}U decay chain. It is important to note that may not be correct for the processed NORM in many circumstances, as during processing of minerals radium and lead/polonium usually behave in different ways.

It is, therefore, essential that in cases where disequilibrium has been clearly established, the analysis for the full set of radionuclides listed in “C” above be carried out.

Without the data for all of the above ten radionuclides from ^{232}Th and ^{238}U decay chains (and, where required, the data for five more radionuclides from the ^{235}U decay chain) it is impossible to determine if material is classified as ‘radioactive’ for transport or not. In some circumstances the data may also be required for other radionuclides such as ^{40}K and ^{87}Rb (part 2.4 above).

It is very important to remember the following:

a. Prior to undertaking a complete analysis (step C above), the measurements of the concentrations of seven radionuclides (step B in this part) should be carried out to initially assess the secular equilibrium of the decay chains.
b. The regular analysis for all radionuclides (i.e., for each shipment) should not be required (a confirmation from the local regulator would be needed); the analyses will only need to be repeated if the feedstock changes, the processing method changes, of both of those change.

2.6. Transport of NORM not in secular equilibrium, calculations when data is available

The equation that is given in the Regulations [6] is:

$$X_m = \frac{1}{\sum_i \frac{f(i)}{X(i)}}$$, where:

f(i) is the fraction of activity concentration of radionuclide ***i*** in the mixture,

X(i) is the appropriate activity concentration limit for exempt material as appropriate for the radionuclide i, which needs to be multiplied by 10 (exemption factor for NORM), and

$\mathbf{X_m}$ is the derived value of activity concentration limit for exempt material.

Instead of detailed and relatively complex explanations on how the Mixtures method is used in calculations, it was considered that the presentation of an actual practical example that can be easily used by the industry and/or regulators will be much more appropriate.

Practical example 3

Mineral concentrate was treated using chemicals and dried in the kiln; it is, therefore, suspected that the secular between radionuclides in ^{232}Th and ^{238}U decay chains has been disrupted. The disruption of secular equilibrium has been confirmed and the concentrations of radionuclides were measured as follows:

Radionuclide	Concentration (Bq/g)	
^{232}Th	6.44	^{232}Tn decay chain is not in equilibrium
^{228}Ra	3.12	
^{228}Th	6.04	
^{238}U	5.33	^{238}U decay chain is not in equilibrium
^{234}Th	7.05	
^{234}U	4.28	
^{230}Th	5.21	
^{226}Ra	6.73	
^{210}Pb	2.15	
^{210}Po	1.18	

First step is to determine which activity concentration limits apply to individual radionuclides, from Table 2 of the Regulations [6] (taking into account the factor of 10 for NORM), sum up the concentrations and update the table, by adding one more column to the right:

see over page

In the second step, we calculate the fraction of the activity, which each radionuclide contributes to the total. For example, ^{232}Th concentration is 6.44 Bq/g. Dividing this value by the sum (47.53 Bq/g) gives the result of 0.135, which is the fraction for ^{232}Th.

Radionuclide	Concentration (Bq/g)	*Concentration limit (Bq/g)*
^{232}Th	6.44	*100*
^{228}Ra	3.12	*100*
^{228}Th	6.04	*10*
^{238}U	5.33	*100*
^{234}Th	7.05	*1000*
^{234}U	4.28	*100*
^{230}Th	5.21	*10*
^{226}Ra	6.73	*100*
^{210}Pb	2.15	*100*
^{210}Po	1.18	*100*
SUM	*47.53*	

Similarly, if we divide 3.12 Bq/g for ^{226}Ra by the same 47.53 Bq/g, we have the value for the fraction of ^{226}Ra, which is 0.066. This is done for each radionuclide and the table is further updated, by adding one more column:

Radionuclide	Concentration (Bq/g)	*Fraction* ***f(i)***	Concentration limit ***X(i)*** (Bq/g)
^{232}Th	6.44	*0.135*	100
^{228}Ra	3.12	*0.066*	100
^{228}Th	6.04	*0.127*	10
^{238}U	5.33	*0.112*	100
^{234}Th	7.05	*0.148*	1000
^{234}U	4.28	*0.090*	100
^{230}Th	5.21	*0.110*	10
^{226}Ra	6.73	*0.142*	100
^{210}Pb	2.15	*0.045*	100
^{210}Po	1.18	*0.025*	100
SUM	47.53		

Now we are at the third step, where we are ready to use the equation from §405 of the Regulations [6], cited above.

The values of f(i) are now available, as well as the values of X(i) for each radionuclide.

To calculate the value of Xm, which is the derived value of activity concentration limit for this specific mix of radionuclides, we divide f(i) by X(i) for each radionuclide and sum all of them, that is the denominator in the equation, where the 1 is the numerator.

The resulting table is as follows:

Radionuclide	Concentration (Bq/g)	Fraction ***f(i)***	Concentration limit ***X(i)*** (Bq/g)	*The limit for this mixture*
^{232}Th	6.44	0.135	100	
^{228}Ra	3.12	0.066	100	
^{228}Th	6.04	0.127	10	
^{238}U	5.33	0.112	100	
^{234}Th	7.05	0.148	1000	
^{234}U	4.28	0.090	100	
^{230}Th	5.21	0.110	10	
^{226}Ra	6.73	0.142	100	$X_m = \frac{1}{\sum_i \frac{f(i)}{X(i)}}$
^{210}Pb	2.15	0.045	100	
^{210}Po	1.18	0.025	100	
SUM	47.53			*33.52*

The last step is to compare the value of the limit for this mix of radionuclides in the specific material to the total calculated in the first step:

47.53 Bq/g > 33.52 Bq/g

Therefore, this material is not exempt and the Regulations [6] apply to its transport.

2.7. Transport of NORM not in secular equilibrium, calculations when data is not available

This method is very inadvisable, but can be used when the detailed information about the concentrations of radionuclides in the material is not available and it is also unknown if both thorium and uranium chains are in secular equilibrium.

Table 3 in §407 of the Regulations [6] suggests the values that should be used in these circumstances.

As the limit for 'total activity' in Bq will always be exceeded in case of a bulk shipment of the material, the attention must be paid to the third column of the Table 3 (*Activity concentration for exempt material*), which has three lines:

Only beta or gamma emitting nuclides are known to be present (10 Bq/g)
Alpha emitting nuclides, but no neutron emitters, are known to be present (0.1 Bq/g)
Neutron emitting nuclides are known to be present or no relevant data are available (0.1 Bq/g)

Please note that the exemption factor of 10 for NORM applied only to the radionuclide concentrations in Table 2, not to the values in Table 3.

As it would be very rare that a mineral to be transported contains only beta and gamma emitting radionuclides nuclides the value of 10 Bq/g should only be used when the absence of alpha emitting nuclides has been conclusively proven. For all other practical purposes that value of 0.1 Bq/g will be applicable.

Practical example 4

The same material as in the practical example 1 above is ready for shipment. The data for the concentrations of radionuclides is not available, the only known value is the concentration of U_3O_8, 40 ppm (34 ppm of uranium). The activity concentration that corresponds to 34 ppm of uranium is 0.42 Bq/g, which is above 0.1 Bq/g, the limiting value specified in Table 3 in §407, the material will not be exempt from Regulations [6].

Which leads to an absurd situation, where the material may be exempt from general radiation protection regulations [17], as the activity concentration is below 1 Bq/g, but will be a subject to the transport safety regulations [6].

A note on practical examples 1 and 4

The cost and the length of time associated with obtaining full radionuclide-specific information for a material should be weighed against the disadvantages of the potentially incorrect classification of this material as radioactive for transport. The suggested approach is to use the partial data (step B in part 2.5 above) and, if it appears that a material is not exempt, carry out the detailed analysis (step C in part 2.5 above).

If the laboratory analysis shows that activity of the material to be transported is very close to the limit (above 9 Bq/g for NORM in secular equilibrium, or the sum of activity concentrations calculated in practical example 3 is above 90% of the limit calculated for this specific mixture of radionuclides, it is always prudent to take additional samples to ensure that at no time the limits are exceeded.

2.8. A note on radionuclides from ^{235}U decay chain

The analysis of the material for the nuclides of 235U decay chain is typically not required for NORM, for the following reasons:

- As natural abundance of ^{235}U is only 0.72%, the values are usually not very important in the determination of the applicability of the regulations;
- Smaller laboratories (at mining and processing sites) would provide the data as

'total uranium' in parts per million for U_3O_8 (without any isotopic analysis), and the small proportion that ^{235}U represents is very often within the margin of typical laboratory errors/ variance.

In some cases, however, measurements of concentrations of ^{235}U decay chain nuclides may be needed. Then (as noted in step C of part 2.5 above) the analysis will be required for the following radionuclides: ^{235}U, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Ra.

Correction Note 3: The previous version of the paper stated that the concentration of ^{235}U could be estimated by multiplying the value of ^{238}U by 0.01, which was incorrect and this method should not be used.

An explanation of correct estimation of ^{235}U concentration based on ^{238}U value is as follows:

The specific activity of ^{238}U is 12,384 Bq/g and ^{235}U – 80,170 Bq/g.

100 grams of uranium contain:

- 99.68 g of ^{238}U and 0.72 g of ^{235}U, and
- 1,234.4 kBq of ^{238}U and 57.7 kBq of ^{235}U.

Therefore, an activity ratio ^{235}U:^{238}U is 4.7%, not 1% and the combined specific activity of U-238 and U-235 is 12.859 Bq/g. If there is a need to theoretically estimate the activity concentration of ^{235}U in NORM and the value is available only for U-238 (not for the U(nat)), the activity concentration of ^{238}U needs to be multiplied by 0.047, not by 0.01.

2.9. Materials with no 232Th or 238U, where only parts of decay chains are present

There are also several cases when there is no thorium and/or uranium in NORM, and only a part of decay chain or individual natural radionuclides may be present in the material that is transported, the examples are:

a. Waste/sludge/scale from oil and gas production, paper/pulp production, geothermal energy generation, water treatment, etc. (where the decay chains start from ^{226}Ra and/or ^{228}Ra);
b. Films from internal surfaces of the gas processing and storage equipment, containing ^{210}Pb;
c. Dust from electrostatic precipitators and filters at coal, iron, copper, etc. smelters, in which ^{210}Pb and ^{210}Po may accumulate in significant concentrations.

In these cases, the limits applicable for individual radionuclides should be used and both a consultation with the Regulatory Authority and specialist advice are highly advisable.

Several examples of the calculations for the three cases above are given below. These calculations are similar to those presented in practical example 3 above.

Practical example 5

The old scale packaged in drums, containing ^{226}Ra at 90 Bq/g, ^{210}Pb at 50 Bq/g and ^{210}Po at 40 Bq/g.

Step 1. Sum the activity concentrations in the mixture for all radionuclides nuclides to obtain the total activity concentration in the mixture: the sum is 180 Bq/g.

Step 2. For each nuclide ***i*** divide the activity concentration, measured for that nuclide, by the sum from Step 1 above, to obtain the fraction of the nuclide ***i*** in the mixture: ^{226}Ra ***f(i)*** = 0.5, ^{210}Pb ***f(i)*** = 0.28, ^{210}Po ***f(i)*** = 0.22.

Step 3. Divide the ***f(i)*** derived above, by the ***X(i)*** – the appropriate limit for this radionuclide from Table 2 of the Regulations [6] (multiplied by the factor of 10, as allowed for NORM): ^{226}Ra = 0.0050, ^{210}Pb = 0.0028, ^{210}Po = 0.0022.

Step 4. Calculate the ***Xm*** value for this particular mixture: ***Xm*** = 100 Bq/g

Step 5. Compare the calculated ***Xm*** value with the measured total activity concentration, calculated in step 1:

Outcome:180 Bq/g > 100 Bq/g – the material is classified as 'radioactive' for transport.

Practical example 6

A box (~15 kilograms) of "fresh" ^{210}Pb films removed from the internal surfaces at a gas storage facility. It is assumed that the levels of radon in natural gas were very high and an additional non-scheduled cleaning activity was undertaken. Thus, due to a relatively short time since previous clean up (~1 month), no ingrowth of ^{210}Po in concentrations requiring assessment is assumed to have taken place and we consider that the material in the box contains exclusively ^{210}Pb at 140 Bq/g.

No use of any equations is required in this case – instead the values given in Table 2 of the Regulations for 210Pb are used in the assessment:

- The activity concentration limiting value is 100 Bq/g, taking into account that the material is NORM,
- The activity limit for the exempt consignment is 10,000 Bq (the factor of 10 does not apply to limits for total activity)

Both limits have to be exceeded for the material to be classified as 'radioactive' for transport: the Regulations apply in this case, as –

- 140 Bq/g > 100 Bq/g, and
- 140 Bq/g 15,000 g = 2,100,000 Bq > 10,000 Bq.

However, as the gamma radiation level from the surface of package is low was (was measured at 1.8 µSv/hour), the box can be transported as an *excepted* package, without radiation labels or placards on the outside surfaces (please see part 2.10 below).

Practical example 7

Several drums of dust collected from electrostatic precipitators and 'bag houses', containing ^{210}Pb at 120 Bq/g and ^{210}Po at 40 Bq/g.

Step 1. Sum the activity concentrations in the mixture for all radionuclides nuclides to obtain the total activity concentration in the mixture: the sum is 160 Bq/g.

Step 2. For each nuclide ***i*** divide the activity concentration, measured for that nuclide, by the sum from Step 1 above, to obtain the fraction of the nuclide ***i*** in the mixture: ^{210}Pb ***f(i)*** = 0.75, ^{210}Po ***f(i)*** = 0.25.

Step 3. Divide the ***f(i)*** derived above, by the ***X(i)*** – the appropriate limit for this radionuclide from Table 2 of the Regulations [6] (multiplied by the factor of 10, as allowed for NORM): ^{210}Pb = 0.0075, ^{210}Po = 0.0025.

Step 4. Calculate the ***Xm*** value for this particular mixture: ***Xm*** = 100 Bq/g

Step 5. Compare the calculated ***Xm*** value with the measured total activity concentration, calculated in step 1:

Outcome: 160 Bq/g > 100 Bq/g – the material is classified as 'radioactive' for transport.

2.10. Excepted packages

There is a possibility that the NORM shipment can be classified as *excepted* package (please note the difference with *exempted* package, when the Regulations do not apply at all).

The main criterion for the determination of the excepted package is given in the §516 of the Regulations:

The radiation level at any point on the external surface of an excepted package shall not exceed 5 microSv/h.

Please note that the measurement is taken on the surface, not at a distance of 1 metre.

The second criterion is adherence to Table 4 of the Regulations and this cannot be ignored. This Table contains activity limits for *excepted* packages and where NORM is concerned, the applicable values are:

- For special form materials 10^{-3} of A_1 value,
- For other form materials 10^{-3} of A_2 value.

The A_1 and A_2 values for different radionuclides are provided in the Table 2 of the Regulations – Basic radionuclide values, where the concentrations and total activity limits are obtained for calculations.

For U(nat) and Th(nat) A_1 and A_2 values are unlimited, therefore the use of values in Table 4 is not required.

This, however, is not the case where the transport of materials containing individual radionuclides is undertaken. The values of A_1 and A_2 are not unlimited for natural radionuclides such as ^{210}Pb, ^{210}Po, ^{226}Ra, ^{228}Ra, ^{228}Th and ^{230}Th and the values given in Table 4 of the Regulations need to be considered.

Practical example 8

The dose rate on the surface of a large package (container) is 2.5 microSv/h (below 5 microSv/h), but the package contains ^{226}Ra and, therefore, A_1

and A_2 values need to be considered.

For ^{226}Ra $A_1=2 \times 10^{-1}$ TBq and $A_2=3 \times 10^{-3}$ TBq, we also need to consider in which "form" the transported material is. The definition is provided in §239 of the Regulations, –
Special form radioactive material shall mean either an indispersible solid radioactive material or a sealed capsule containing radioactive material.

The material in the package is the solid scale from oil and gas industry, therefore we can consider that the form is "special", to which the limit of 10^{-3} of A_1 value applies, as per Table 4.

The A_1 value is 0.2 TBq (200 GBq) and, after applying the factor from Table 4, the limiting value for this specific package is 0.2 GBq of ^{226}Ra.

The amount of ^{226}Ra in the package needs to be estimated and compared with the limit of 0.2 GBq. One gram of ^{226}Ra equals 3.7×10^{10} Bq (37 GBq) and in some cases there would be more than one gram of ^{226}Ra in a large package containing scale from oil and gas industry; and, most definitely more than 5.5 mg of it (which equals to 0.2 GBq).

Therefore, despite the fact that the surface dose rate from the package is significantly below 5 microSv/hour, that package cannot be classified as *excepted* and must be labelled/placarded in accordance with the Regulations.

Practical example 9

If the material contains about 15 Bq/g of Th(nat) a radiation level from its surface will be approximately 7 µSv/hour.

If, however, (a) the thickness of the wall of the trailer used for the transport of this material is increased, or (b) bags or drums used for the transport of the material are placed inside a container relatively far from all external surfaces (including top and bottom), the surface radiation level from the package would be lowered to approximately 3-4 µSv/hour, and the material can be classified as *excepted* package. As the material is Th(nat), the limiting values from Table 4 of the Regulations do not apply.

§515 of the Regulations [6] provides details of markings required for an excepted package: *Packages shall bear the marking "RADIOACTIVE" on an internal surface in such a manner that a warning of the presence of radioactive material is visible on opening the package.*

§531 further describes required markings: *In the case of excepted packages, other than those accepted for international movement by post, only the United Nations number, preceded by the letters "UN", shall be required.*

The illustration of such signposting is Figure 7 of the Regulations [6].

Based on the data provided in Table 1 of the Regulations [6], in the case of the transport of NORM as an *excepted* package the load/container will be marked only with 'UN2910' instead of any "radioactive" labels or placards.

The sign, similar to the one given in Figure 6 of the Regulations [6] will, however, be required to be visible when, for example, a container is opened (the word "RADIOACTIVE" must be clearly visible upon opening the package).

This method is commonly used to transport NORM mineral exploration samples to the laboratory, where the concentrations of radionuclides are not known, but gamma radiation level from the surface of the package can be measured.

3 PRACTICAL CONSIDERATION IN THE TRANSPORT OF NORM

3.1. Procedure to follow

After it has been determined that the material to be transported is classified as 'radioactive' in accordance with the Regulations [6], several steps need to be taken to ensure that both transport documentation and associated labels/placards are fully compliant with the requirements.

The following usually takes place:

- The carrier must possess an appropriate licence to transport radioactive material.

- Three copies of the appropriate transport declaration are prepared by a responsible person (typically a radiation safety officer). Two copies are provided to the driver (one stays with the transporting company, another is for the receiver of the material), the third copy is kept by the responsible person. In the case of multiple transport of the same material a 'standing declaration' could be acceptable, provided that prior agreement has been reached with the Regulatory Authority.
- Appropriate training must be provided to all workers involved in the transport, loading and unloading the material, in accordance with §§311-315 of the Regulations [6].
- The material must be accurately classified and the appropriate placards should be placed on the vehicle, in accordance with §§530-532, 537-540 and 543-544 of the Regulations [6].

3.2. Determination of the Transport Index

The first step is the determination of the Transport Index (TI), in accordance with §523 of the Regulations [6]:

(a) Determine the maximum dose rate in units of millisieverts per hour (mSv/h) at a distance of 1 m from the external surfaces of the package, overpack, freight container or unpackaged LSA-I, SCO-I and SCO-III. The value determined shall be multiplied by 100.

…

(b) For tanks, freight containers and unpackaged LSA-I, SCO-I and SCO-III, the value determined in step (a) shall be multiplied by the appropriate factor from Table 7.

The SCO-III category does not apply to NORM, it applies to very large objects (typically steam generators from nuclear power plants) which are too large to be placed inside any transport package.

Please note that the measurement of gamma radiation level is to be carried out at a distance of 1 metre from the package, not on its surface.

Practical example 10

Measured radiation level at 1 metre from the truck containing radioactive mineral concentrate is 3 microSv/hour (0.003 millisieverts per hour) gives the transport index as 0.3. The values in Table 7 are given in m^2 for the largest cross-sectional area of the load being measured. For large road trains it is prudent to assume that the value associated with the size of the load >$20m^2$ will be applicable and the multiplication factor will be 10. For a single truck a different value will apply (associated with the size of the load >$5m^2$, but < $20m^2$), and the multiplication factor will be 3.

Therefore, if material is transported in a truck with a single trailer, the transport index will be 0.9, if a large road train is used, the transport index will be 3.

It should be noted that §523(a) of the Regulations provides default *maximum dose rate at any point 1m from the external surface for uranium and thorium ores and their concentrates*. These values are very high and should only be used when a gamma radiation monitor is not available for direct measurement. For example, the value of 400 µSv/hour is assumed for ores and physical concentrates of uranium and thorium, when in practice is highly unlikely that levels above 150 µSv/hour would be measured.

When the material is transported in multiple drums inside one container (for example, in the process of shipment of tantalum concentrates), the gamma radiation dose rate needs to be measured from the container. Measuring radiation levels from each individual drum is likely to result in an incorrect determination of the Transport Index, as this process will not take into account the shielding offered by the walls of the container and, sometimes, also by the drums with ballast material that may also be placed inside a transport container.

3.3. Selection of the correct transport label/ placard

The category of the shipment is determined based on the Transport Index (TI) and the radiation level on external surface, in accordance with §529 and Table 8 of the Regulations [6].

Please note the difference: Transport Index is determined by measuring radiation levels at a distance of 1 metre from the package, for categorisation of the load the measurement on the surface is also required.

The illustrations for the labels are provided in Figure 1 and the process of the selection of the correct one is provided below.

Figure 1. Transport labels (reproduced from Figures 2, 3 and 4 of the Regulations [6])

The process of selection:

- If TI is not more than 0.05, and the surface radiation level is below 5 µSv/hour, the category of the label will be I-WHITE (unless the package is *excepted*, when label is not required);
- If TI is more than 0 but less than 1, and the surface radiation level is above 5 µSv/h, but below 500 µSv/h, the category of the label will be II-YELLOW;
- If TI if more than 1 but less than 10, and the surface radiation level is more that 500 µSv/h, the category of the label will be III-YELLOW;
- III-YELLOW category is also used if material is transported under special arrangement, please refer to §238 of the Regulations [6].

In minerals industry, the typical categories will be I-WHITE, II-YELLOW and, occasionally, III-YELLOW.

It is highly unlikely that surface gamma radiation levels measured from naturally occurring radioactive materials will exceed 300-350 µSv/h. Due to the use of the multiplication factor for large loads, it is expected that the primary criterion for the selection of the correct label for minerals industry will be the Transport Index (TI) and not the surface radiation level, as detailed in §529(a) of the Regulations [6]:

Where the TI satisfies the condition for one category but the surface dose rate satisfies the condition for a different category, the package, overpack or freight container shall be assigned to the higher category.

§529 of the Regulations needs to be considered together with §523 (described in part 3.2 above), which provides two options:

- Measuring the actual value of Transport Index, or
- Using the values for uranium and thorium ores and concentrates, provided in §§523(a)(i)-(iii).

The typical practice in uranium mining and processing is to transport uranium concentrate as LSA-I (please see part 3.5) with YELLOW-III label, and TI of 6, using the 0.02 mSv/h value provided in §523(a)(iii), multiplied by the factor of 3 for a typical 20-foot container. For ores and low-grade concentrates containing naturally occurring radionuclides it is advisable to always use measured values, as gamma dose rates will not be as high as the default values.

3.4. Notes on the exclusive use arrangement

The bulk (unpackaged) materials in the minerals industry may only be transported under the exclusive use arrangement, as per §520(b) of the Regulations [6]:

LSA material and SCO in groups LSA-I, SCO-I and SCO-III may be transported, unpackaged, under the following conditions:

(b) Each conveyance shall be under exclusive use, except when only transporting SCO-I on which the contamination on the accessible and the inaccessible surfaces is not greater than 10 times the applicable level specified in para. 214.

The definition of exclusive use is given in §221:

Exclusive use shall mean the sole use, by a single consignor, of a conveyance or of a large freight container, in respect of which all initial, intermediate and final loading and unloading and shipment are carried out in accordance with the directions of the consignor or consignee, where so required by these Regulations.

Further information is provided in para 221.1 of the Advisory Material [9]:
The special features of an 'exclusive use' shipment are: that a single consignor makes the shipment and has, through arrangements with the carrier, sole use of the conveyance or large freight container; and that all initial, intermediate and final loading and unloading and shipment of the consignment are carried out only in strict accordance with directions from the consignor or consignee.

It is very uncommon for a truck transporting radioactive mineral from 'A' to 'B' to deviate for a delivery of another material (such as fertiliser) for a different company from 'B' to 'A'. Therefore, if a truck transports mineral concentrate from a mine site to a processing plant and then is used by the same company to transport processing tailings back to a mine site it does so under the exclusive use arrangement.

The main advantage of that arrangement is that, in accordance with §§513 and 514 of the Regulations [6], there is no need to decontaminate the internal surfaces of the conveyance after each shipment.

It is also important to note that –

a In accordance with §546(m), the transport declaration must contain the statement "EXCLUSIVE USE SHIPMENT", and

b In accordance with §526 if the value of Transport Index (TI) exceeds 10, it can only be transported under the exclusive use arrangement.

3.5. Determination of the class of low specific activity (LSA) material

The definition of LSA (low specific activity) material is provided in §226 of the Regulations [6]:
Low specific activity (LSA) material shall mean radioactive material that by its nature has a limited specific activity, or radioactive material for which limits of estimated average specific activity apply. External shielding materials surrounding the LSA material shall not be considered in determining the estimated average specific activity.

In accordance with §409 of the Regulations [6] most materials transported in the minerals industry will be classified as LSA-I.

§409(a)(i) and (ii) clarifies that NORM is classified as LSA-I:
Uranium and thorium ores and concentrates of such ores, and other ores containing naturally occurring radionuclides.
Natural uranium, depleted uranium, natural thorium or their compounds or mixtures, that are unirradiated and in solid or liquid form.
409 (iii) Radioactive material for which the A_2 value in unlimited, fissile material may be included only if excepted under paragraph 417.

As noted above, for many natural radionuclides the A2 value is not unlimited and the following needs to be considered:
^{226}Ra and ^{228}Ra would not be present in ores and concentrates in "significant" amounts, even in the case of transport of contaminated items from oil and gas industry. One of the cases where the package would be classified as LSA-II is a full container of drums with scale that contains predominantly ^{226}Ra and ^{228}Ra. In this case the amount of this radium isotope may be "significant" and the local Regulatory Authority must be contacted for advice.

The definition from §409(a)(iv) may be used for all NORM that is not an "ore" or a "concentrate", such as waste/residues/sludge/etc:
Other radioactive material in which the activity is distributed throughout and the estimated average specific activity does not exceed 30 times the values for the activity concentration specified in paras 402–407.

Correction Note 4: The previous version of this paper [1] contained an incorrect assumption that '10-times' exemption factor for NORM can be used in the interpretation of the limit in §409(a)(iv) and the limiting value for U(nat) and Th(nat) is 300 Bq/g.

This is not correct and the limiting value for the classification of shipments of materials containing U(nat) and/or Th(nat) as LSA-I is 30 Bq/g, not 300 Bq/g.

Practical example 11

If the activity of the material (U(nat) and Th(nat) combined) to be transported is less than 30 Bq/g, the marking "LSA-I" should be used on the transport label/placard. If, however, the value exceeds 30 Bq/g, the marking should be "LSA-II".

Practical example 12

Taking into account that the limiting value for ^{226}Ra in the Table 2 of the Regulations is 10 Bq/g and without the application of the '10-times' exemption factor for NORM:

- The scale containing 290 Bq/g of ^{226}Ra will be classified as LSA-I, but
- The scale containing ^{226}Ra in concentration of 310 Bq/g will be classified as LSA-II; therefore, additional safety measures may need to be taken in the process of its transport.

3.6. Determination of the information that needs to be on the transport label/placard

There appear to be many misinterpretations of signposting requirements, especially in the transport of NORM materials in bulk using road transport, particularly in regards to the use of UN numbers and selection of correct information for the transport labels and placards:

- The LABEL is small in size, 10x10 cm.
- The PLACARD is larger in size, 25x25 cm.

The §543 of the Regulations [6] states, with added highlight:

Large freight containers carrying unpackaged LSA-I material or SCO-I or packages other than excepted packages, and tanks shall bear four placards that conform to the model given in Fig.6. The placards shall be affixed in a vertical orientation to each side wall and to each end wall of the large freight container or tank.

Any placards that do not relate to the contents shall be removed. Instead of using both labels and placards, it is permitted, as an alternative, to use enlarged labels only, where appropriate, as shown in Fig.2–4, except having the minimum size shown in Fig.6.

As a result:

- If there are several packages with radioactive material in the vehicle (for example, in the one that is transporting radioactive samples to or from a laboratory), each of the packages is LABELLED, and the vehicle itself is PLACARDED.
- Full compliance with the Regulations [6] requires placing both labels and placards on the vehicles; but there is a provision in §543 (cited above) that instead of putting those side-by-side, the LABEL can be enlarged to 25x25cm size and is used instead of a PLACARD, on all four sides of a container.

The note to the Figure 2 (Figure 6 in the Regulations) illustrating the PLACARD states,

The use of the word "RADIOACTIVE" in the bottom half is optional, to allow the alternative use of this placard to display the appropriate UN number for the consignment.

An illustration is provided in Figure 3 below.

Figure 2. Transport placards (reproduced from Figures 6 and 7 of the Regulations [6])

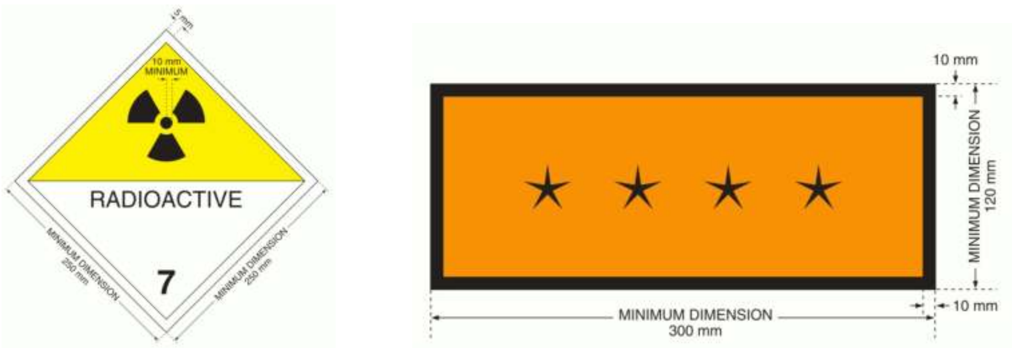

Figure 3. Transport placards

It is important to note that:

- The replacement of the word "RADIOACTIVE" can be done for PLACARDS only,
- This option is not available for LABELS, even if they are enlarged ones and are used instead of PLACARDS.

Practical example 13

If the vehicle is used to transport radioactive mineral samples in steel drums (type A containers):

- Each drum is LABELLED as per Figure 1, as required;
- The vehicle itself is PLACARDED as per Figure 2, the word "RADIOACTIVE" may be replaced with UN2912, or UN3332, as needed (please refer to Table 1 of the Regulations [6] to select the correct UN number).

Practical example 14

If the vehicle is used to transport small surface contaminated objects in several packages:

- Each package is LABELLED as per Figure 1, as required;
- The vehicle itself is PLACARDED as per Figure 2; the word "RADIOACTIVE" may be replaced with UN2913.

Practical example 15

There are two options in cases where the vehicle is used to transport bulk NORM:

Option 1:

- The enlarged LABEL is placed on it as required;
- The word "RADIOACTIVE" may not be replaced with UN2912, UN3321 or UN3322, as required;
- On the LABEL the contents may be simply "LSA-I", as per §540(a)(ii), but only if the material is classified as such;
- If material is classified as LSA-II or LSA-III, the data on the radioisotope is required;
- Transport Index will need to be measured with the gamma monitor, as per §523(a). Then, in accordance §523(b) a multiplication factor for loads of different sizes from Table 7 of the Regulations will need to be used. The details are provided in part 3.2

Option 2:

- Both LABELS and PLACARDS are placed on the vehicle as required;
- The word "RADIOACTIVE" on the PLACARD may be replaced by UN2912, UN3321 or UN3322;
- The word "RADIOACTIVE" may not be replaced by the UN number from Table 1 of the Regulations [6] on smaller LABELS; they will also need to contain the information on the contents of the material and the

Transport Index.

An alternative method is provided in §544 of the Regulations, as follows:

Where the consignment in the freight container or tank is unpackaged LSA-I or SCO-I or where a consignment in a freight container is required to be shipped under exclusive use and is packaged radioactive material with a single UN number, the appropriate UN number for the consignment (see Table 1) shall also be displayed, in black digits not less than 65 mm high, either:

(a) In the lower half of the placard shown in Fig. 6 and against the white background; or
(b) On the placard shown in Fig. 7.

When the alternative given in (b) is used, the subsidiary placard shall be affixed immediately adjacent to the main placard shown in Fig. 6, on all four sides of the freight container or tank.

The alternative placard is illustrated in Figure 4 and an advice from the Regulatory Authority is required in regards to the correct signposting/ placarding of the shipment.

In many practical cases at least one placard on the vehicle/package contains the word 'RADIOACTIVE' (as in Fig.6 of the Regulations) and subsidiary placards are either the ones as in Fig.7 of the Regulations) or the alternative ones, i.e., similar to Figure 4 below.

Figure 4. Alternative placard

3.7. Practical considerations for signposting and placards

Detailed data on marking, labelling and placarding of loads are provided in §§531–540 and 543–545 of the Regulations [6]. There are two important points on the placement of placards:

Location

§571 of the Regulations [6] specify that:
Vehicles carrying packages, overpacks or freight containers labelled with any of the labels shown in Figs 2–5, or carrying unpackaged LSA-I material, SCO-I or SCO-III, shall display the placard shown in Fig. 6 on each of:
(a) The two external lateral walls in the case of a rail vehicle;
(b) The two external lateral walls and the external rear wall in the case of a road vehicle.

§543.1 of the Advisory Material [9] provides an additional comment:
Placards, which are used on large freight containers and tanks (and on road and rail vehicles (see para. 571 of the Transport Regulations)), are designed in a similar way to the package labels… in order to identify clearly the hazards of the dangerous goods. Displaying the placards on all four sides of the freight containers and tanks ensures ready recognition from all directions. The size of the placard is intended to make it easy to read, even at a distance. To prevent the need for an excessive number of placards and labels, an enlarged label may only be used on large freight containers and tanks where it also serves the function of a placard.

Definition of the vehicle

The definition of the vehicle, provided in §248 of the Regulations [6] should be taken into account prior to arranging the transport of minerals by road and rail:
Vehicle shall mean a road vehicle (including an articulated vehicle, i.e., a tractor and semi-trailer combination), railroad car or railway wagon. Each trailer shall be considered as a separate vehicle.

Practical example 16

A road train (two trailers or semi-trailers hauled by a prime mover) will need to have six placards: one each at the front and at the back, and two on each side. A longer road train, however, (for example, a truck with three trailers) will require eight placards (two more on the extra trailer). Please note that placard at the front is optional, in accordance with §571(b) of the Regulations [6].

In the case of transporting radioactive material by rail in several carriages each carriage will need two signs on each side and, in case of the carriage with radioactive material is the last one, it is recommended to have a sign at the rear of this carriage as well.

3.8. Practical considerations for blending of different NORM in one conveyance

There are two possibilities of blending/mixing the material:

a) Several different materials are simultaneously collected in one storage bin prior to transport and then loaded into a vehicle; and
b) Several different materials are loaded separately into a vehicle, one after another.

The method (b) above cannot be used in practice, as described below.

There are no specific notes in Regulations [6] explicitly prohibiting the practice. There are, however, three main reasons for it not to be used, unless activity concentrations of blended materials do not differ more than by a factor of ten, which is introduced in §409.11 of the Advisory Material [9],
For material in which the activity is required to be distributed throughout…, a simple method for assessing the average specific activity is to divide the volume occupied by the LSA material into defined portions and then to assess and compare the specific activity of each of these portions. A difference in specific activity between portions of a factor of less than ten should cause no concern.

Please note that in case of the transport of LSA-III material the activity concentrations should not differ more than by a factor of three, in accordance with §409.15 of the Advisory Material [9].

1) Impossibility of determining the specific activity of the material in accordance with §240 of the Regulations:
Specific activity of a radionuclide shall mean the activity per unit mass of that nuclide. The specific activity of a material shall mean the activity per unit mass of the material in which the radionuclides are essentially uniformly distributed.

2) Impossibility of the correct classification of the material, in accordance with the definition of LSA-I in §226 of the Regulations [6].
Low specific activity (LSA) material shall mean radioactive material that by its nature has a limited specific activity, or radioactive material for which limits of estimated average specific activity apply.

§236.2 of the Advisory Material [9] provides an additional clarification:
If the activity concentration varies across packages within the consignment or across inner containment systems or receptacles within the packages, the highest activity concentration should be considered as the activity concentration of the consignment.
The uniform distribution cannot possibly be achieved when different NORM is loaded into a vehicle separately. One NORM may be exempt from the Regulations [6], but if another NORM may not be, then the highest activity concentration will need to be used in the classification and signposting of the transport of blended material.
It is *theoretically* possible to dilute the ‘radioactive’ material with ‘less radioactive’ one, provided that their specific activities do not differ more than by a factor of 10 a factor of 3 for LSA-III).

3) The Transport Index of the package is determined by measuring of the maximum radiation level at a distance of 1 metre and categorisation is carried out by measuring of the maximum surface radiation level, as detailed in part 3.2. A practical example describes the potential challenges.

Practical example 17

If 2 tonnes of monazite concentrate (specific activity of 90 Bq/g) are placed on the bottom of the trailer and then covered with 22-23 tonnes of the material with much lesser activity, for example, sand processing tailings with specific activity of 2 Bq/g:

- The specific activity and class of the material cannot be determined by simple averaging, as the activity concentrations differ by a factor that is more than 10, therefore, the radionuclides are not uniformly distributed.
- The measured maximum radiation levels at both 1 metre and on the surface will still be high enough at some locations to require appropriate placarding of the truck.

If, however, a material with a specific activity of 15 Bq/g is mixed with the same sand tailings containing 2 Bq/g, the radionuclides in this NORM may be considered uniformly distributed and the overall specific activity of the load can be calculated. It is also likely that the surface radiation level from a vehicle/ container will be less than 5 µSv/hour. In this case, transporting of the mixed material as an 'excepted package' is possible, at least in theory.

However, given the gamma radiation levels at the distance of 1 metre from the truck will be very different and the determination of the correct Transport Index will be, therefore, problematic.

There is also an uncertainty on how the surface radiation levels, that are required for the categorisation of the material for transport (part 3.3 above) should be measured. In theory, the measurements should be done not only on the side surfaces, but also on the bottom and top of the load. In this case any options to transport a material with activity concentrations above 10 Bq/ g as 'excepted package' after blending of materials in the truck appear to be impractical.

Practical example 18

Discussion about the possibility of blending of different materials directly inside the truck/trailer in regards to heavy minerals sands (considering that by prior arrangement with an appropriate Regulatory Authority the measurement of the surface gamma radiation levels from the bottom of the trailer would not be required):

If, as in practical example 17, we consider blending of monazite concentrate (90 Bq/g) with sand tailings (2 Bq/g), the outcome will depend on the amount of monazite concentrate that was placed in the truck prior to covering it with 'other' tailings.

If it is only an about 2 m^3 pile in the centre of the trailer and the material does not touch the walls from the inside, there is a possibility that this load could be an 'excepted package' (measurements will have to be carried out in any case). Basically, unless these 2-3 m^3 are positioned directly in the middle of the trailer and are separated from the walls from all sides, the Regulations [6] will apply.

Even if this method is considered in theory, it will be quite impossible to implement in practice, as a slight inaccuracy in positioning of the 'radioactive material' in the middle of the trailer or minor overloading will require for the trailer to be emptied and the operation repeated. Additionally, irrelevant of how accurate the positioning and amount of the material in the middle of the trailer may be, the sandy material will undoubtedly move to at least one side of the trailer during the travel to another storage bin for the loading of 'less radioactive' material.

3.9. Surface contamination, definitions

A different issue is associated with the fact that there are no special provisions for NORM in the Regulations [6] in regards to surface contamination. In case of heavy mineral sands, rare earths, tin and tantalum, if even a 1-mm thick layer of NORM is present on the surface of an item to be transported, it is likely that this item will be classified as a Surface Contaminated Object (SCO).

§214 of the Regulations [6] and §214.3 the Advisory Material [9] define 'surface contamination':

Contamination shall mean the presence of a radioactive substance on a surface in quantities in excess of 0.4 Bq/cm^2 for beta and gamma emitters

and low toxicity alpha emitters, or 0.04 Bq/cm² for all other alpha emitters. [6]
Any surface with levels of contamination not exceeding 0.4 Bq/cm² for beta and gamma emitters and low toxicity alpha emitters or 0.04 Bq/cm² for all other alpha emitters is considered a non-contaminated surface in applying the Transport Regulations. For instance, a non-radioactive solid object with levels of surface contamination lower than the above levels is beyond the scope of the Transport Regulations and no requirement is applicable to its transport. [9]

The definition of 'Low toxicity alpha emitters' is given in §227 of the Regulations [6]:
Low toxicity alpha emitters are: natural uranium, depleted uranium, natural thorium, uranium-235, uranium-238, thorium-232, thorium-228 and thorium-230 when contained in ores, or in physical and chemical concentrates; or alpha emitters with a half-life of less than 10 days.

Therefore, when the level of surface contamination exceeds 0.4 Bq/cm² the Regulations apply to the transport of such items on public roads.

Typically, objects that may have surface contamination due to NORM will have only 'low toxicity' alpha-emitters – with a notable exception of ^{226}Ra.

^{226}Ra is not classified as a 'low toxicity' alpha emitter and, whilst the limit of 0.4 Bq/cm² generally applies to all NORM, in a specific situation (e.g., when transporting some contaminated items from oil/gas industry, from the plants for the production of uranium concentrate, tantalum, some rare earth minerals, etc), the limit of 0.04 Bq/cm² may be applicable for the classification of surface contaminated objects.

There always will be alpha emitting isotopes present in surface contamination in minerals industry dealing with NORM. There are some special cases in gas industry and titanium pigment production when beta-emitting ^{210}Pb and ^{228}Ra are present and there are almost no alpha-emitters (examples are fresh ^{210}Pb films formed inside gas processing and storage vessels, and ^{228}Ra scale in titanium pigment plants). But normally it is assumed that alpha-emitting radionuclides are always present, taking into account the fact that there will be an ingrowth of alpha-emitting ^{210}Po from ^{210}Pb, and alpha-emitting ^{228}Th from ^{228}Ra, within a few months.

The level of 0.4 Bq/cm² is the one where the vehicles may need to be signposted as carrying surface contaminated objects, SCO-I. This level applies unless it is confirmed that the material on the surface contains a significant proportion of ^{226}Ra, in which cases the signposting is needed at levels above 0.04 Bq/cm².

In the following discussion it is assumed that most of contamination on surfaces of objects from NORM mines and plants contains ^{226}Ra in an 'overall mix' and that only "low toxicity alpha emitters" are present.

In accordance with §413 of the Regulations [6] there are different values for non-fixed and fixed surface contamination. In mining and mineral processing all surface contamination is usually considered to be "non-fixed", since it can be removed in almost all cases, if there is a real need for it.

The §413(a)(i) states that SCO-I is any object with the levels up to 4 Bq/cm², and §413(b)(i) – that SCO-II is any object with the levels up to 400 Bq/cm². SCO-III classification is not considered to be relevant for NORM.

Thus, it may be concluded that there are four types of surface contaminated objects that can be classified in accordance with alpha surface contamination levels (226Ra excluded):

- < 0.4 Bq/cm² – not contaminated, no signposting required, item is not an SCO;
- > 0.4 Bq/cm², but < 4 Bq/cm² – SCO-I signposting required;
- > 4 Bq/cm², but < 400 Bq/cm² – SCO-II signposting required;
- > 400 Bq/cm² – SCO-III signposting required, but values of this kind are very unlikely to be measured in mining and mineral processing. Even if any are found, it should be relatively easy to remove at least some of the contamination to lower the value

to be below 400 Bq/cm^2.

Therefore, if any object is found to have surface contamination in excess of 0.4 Bq/cm^2 it will need to be transported in accordance with the requirements of the Regulations [6].

3.10. Surface contamination, practical considerations

Potentially all equipment and buildings used in the processing of NORM may become 'surface contaminated objects' and it is important to ensure that no contaminated equipment and/or scrap metal is re-used in other industries and/or melted.

In mining and minerals processing industry it would be impractical to carry out wipe tests and send them to be analysed in a laboratory; therefore, simple surface contamination tests are carried out. In case of a single object only one or two measurements will be required; but in case of a truck already filled with numerous potentially contaminated items many separate tests will need to be done. Therefore, it is advisable to survey the items prior to the loading of the vehicle.

A simple check of gamma radiation levels in the vicinity of a potentially contaminated item may reveal the presence of radioactive material on internal and/or external surfaces. When gamma radiation levels at a distance of 1 metre of an item are measurably higher than the background level in the area, it is highly likely that an item will be classified as 'surface contaminated object'.

Surface contamination measurements that typically follow the measurement of gamma radiation levels:

- A monitor capable of measuring surface contamination should be available;
- A monitor should be appropriately calibrated, i.e., the certificate should state a conversion factor between obtained cpm (counts per minute) and the value in Bq/cm^2;
- A monitor should have a window that can be opened and closed, shielding the probe from damage;
- Measurements are typically carried out over a one-minute interval in a close proximity to the surface (less than 5 mm);
- It is necessary to ensure that material is dry before surface contamination readings are carried out. Two measurements are taken, first with the window closed (that will be a 'background' reading), second, with the window open, and two values in 'counts per minute' obtained;
- The 'background' value should then be subtracted from the second reading and the result compared with the limits specified in the Regulations [6] (using the conversion factor for a particular monitor).

There are three more paragraphs in the Regulations [6] that need to be considered:

§508. The non-fixed contamination on the external surfaces of any package shall be kept as low as practicable and, under routine conditions of transport, shall not exceed the following limits:

a) 4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters;

b) 0.4 Bq/cm^2 for all other alpha emitters.

This paragraph addresses the packages, not the items themselves. It is irrelevant what is being transported and how it is packaged (it may be SCO-I or SCO-II, items inside a container or in a sealed truck, for example), but the limits from §508 for the levels on the outside surfaces of these 'packages' should not be exceeded.

§520. LSA material and SCO in groups LSA-I and SCO-I may be transported, unpackaged, under the following conditions:

a) All unpackaged material other than ores containing only naturally occurring radionuclides shall be transported in such a manner that under routine conditions of transport there will be no escape of the radioactive contents from the conveyance nor will there be any loss of shielding.

b) Each conveyance shall be under exclusive use, except when only transporting SCO-I on which the contamination on the accessible and the inaccessible surfaces is not greater than 10 times the applicable level specified in para. 214.

c) For SCO-I where it is suspected that non-fixed contamination exists on inaccessible surfaces in excess of the values specified in para. 413(a)(i), measures shall be taken to ensure that the radioactive material is not released into the conveyance.

The radiation safety provisions for SCO-I are less stringent than for SCO-II:

- SCO-II could only be transported appropriately packaged.
- SCO-I could be transported unpackaged, unless, as §520(b) states, the surface contamination levels reach ten times of the ones in §214. Which then make this item an SCO-II, in accordance §413(b)(i).
- If it is suspected (not proven, only suspected) that there may be some non-fixed contamination on inaccessible surfaces of SCO-I objects being transported in excess of values in §413(a)(i), making this item potentially SCO-II: one needs to take measures that the material from the inside of the objects cannot 'escape from the conveyance'.

An example is the transport of contaminated pipes from oil production: the pipe may be 8-10 meters long and there is typically no equipment and no possibility to measure what surface contamination may be inside of the pipe, some 4-5 meters "in". Then the plastic or metal caps are placed on each end of the pipe to make sure that no material may fall out from these pipes when they are transported.

Lastly, following from §520 above: after the transport, a vehicle used for this purpose will need to be decontaminated to much lower levels.

§505. Freight containers, IBCs, tanks, as well as other packagings and overpacks, used for the transport of radioactive material shall not be used for the storage or transport of other goods unless decontaminated below the level of 0.4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters and 0.04 Bq/cm^2 for all other alpha emitters.

§505 of the Regulations [6] provides guidance on what items may be suitable for the release of items to other industries and to the general public. It should be noted that in this case, especially in regards to the possible radiation exposure of the members of the general public, the lower value (0.04 Bq/cm^2) is much more appropriate.

Further information on issues associated with surface contamination and a detailed technical advice can be found in IAEA TECDOC-1449 [18.

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