Application of the Regulations for the Safe Transport of Radioactive Material to Bulk Shipments of Materials in Minerals Industry

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The following discussion is based on the IAEA Regulations for the Safe Transport of Radioactive Material (TS-R-1, 2005)[1] and Advisory Material for these Regulations (TS-G-1.1, 2003)[2]. There were many amendments to the first issue of TS-R-1 (1996-2000) [3], several changes were also made when the Regulations were adopted in Australia [4]. These points are highlighted with marks [→] **[→?]**. The mark [→] indicates that there is a difference in wording between 2000 and 2005 editions, the mark **[→?]** indicates that if in a particular jurisdiction 1996-2000 Transport Regulations are in force, additional consultation with an appropriate regulatory authority is required.

1. Determination of the applicability of the Regulations

The first step is to establish if Regulations [1,2] apply to the movement of potentially radioactive material. If the transport is within the boundaries of a mining/processing site, the Regulations are not applicable, in accordance with para 107(b):

107. The Regulations do not apply to:

...

(b) radioactive material moved within an establishment which is subject to appropriate safety regulations in force in the establishment and where the movement does not involve public roads or railways;

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

2. Determination of activity concentration and exemptions

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

Table 1 in Section IV – "Activity Limits and Material Restrictions" gives the values for Th (nat) and U (nat) at 1.0 Bq/g each (paras 401-406). (The value of 1 Bq/g refers to the parent of each decay series, i.e. ^{232}Th and ^{238}U.)

Para 107 provides an exclusion for most materials handled and transported by the minerals industry:

107. The Regulations do not apply to:

...

(e) natural material and ores containing naturally occurring radionuclides that are either in their natural state, or have been processed only for purposes other than for the extraction of the radionuclides, and that are not intended to be processed for use of these radionuclides, provided that the activity concentration of the material does not exceed 10 times the values specified in para. 401(b), or calculated in accordance with paras 402–406;

[→?] – application of the exclusion, different words in [1], [3] and [4]

Therefore, the actual limits for the minerals and associated products are raised to 10 Bq/g for Th (nat) and U (nat). (The value of 10 Bq/g refers to the aggregate activity concentration of ^{232}Th and ^{238}U.)

2.1. Material that has not been a subject of chemical or thermal processing

It is very unlikely that secular equilibrium for both thorium and uranium chains is disrupted during the simple physical concentration/separation of mineral concentrates, such as, for example, gravimetric separation of heavy mineral sands.

The following equation is used to estimate the activity of the material, based on 'parts per million' (microgram per gram) figures typically obtained by laboratory analysis, and assuming that thorium and uranium are 100% of ^{232}Th and ^{238}U respectively:

Th (μg/g) * 4.09x10^{-3} Bq/μg ^{232}Th + U (μg/g) * 1.25x10^{-2} Bq/μg ^{238}U = activity of the material (Bq/g).

Practical example No.1: if the material contains 980 ppm Th and 250 ppm U, the calculation will be:

$$980*4.09\text{x}10^{-3} + 250*1.25\text{x}10^{-2} = 7.1 \text{ Bq/g}$$

2.2. Material that has been a subject of chemical or thermal processing

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

a) Any chemical processing of the material, such as leaching or adding flotation agents to the process;
b) Any thermal processing of the material. Due to the variety of different materials in the industry 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 250-300^{o}C is suggested as a general guide at which additional analysis of the material may be required.

2.2 (a) If the complete analysis of the material has been carried out

Typically, the analysis of the material for some isotopes in both thorium and uranium chains is carried out. In some cases the results for each and every radionuclide in each chain are also obtained. As this may be a very long and costly exercise, the simplified method, based on the half-lives of different isotopes (reflected in para 406 and in the footnote (b) to the Table 1 of the Regulations [1]) is offered:

- For thorium chain, the data is required for ^{232}Th, ^{228}Ra, ^{228}Th (and ^{212}Bi or ^{212}Pb).
- For uranium chain, the data is required for ^{238}U, ^{230}Th, ^{226}Ra, (and ^{210}Bi or ^{210}Pb).
  Note: In case of thermal processing the data for Bi isotopes are also desirable.

[→]

Taking into account the "10-times exemption factor" described above, exemption values for these six radionuclides will be as follows:

- ^{232}Th = 100 Bq/g, ^{228}Ra = 100 Bq/g, ^{228}Th = 10 Bq/g, ^{212}Bi (or ^{212}Pb) = 100 Bq/g.
- ^{238}U = 100 Bq/g, ^{230}Th = 10 Bq/g, ^{226}Ra = 100 Bq/g, ^{210}Bi (or ^{210}Pb) = 100 Bq/g.

There are several ways of specific activity calculation; out of which the 'Ratio method' is the easiest.

Step 1: For each nuclide present, calculate the ratio: $\left(\frac{C_i}{X_i}\right)$, where *C(i)* is the concentration of nuclide *i* and *X(i)* is the appropriate limit from the Table 1 of the Regulations (taking into account the material is 'natural').

Step 2: Sum these ratios over all nuclides: $\sum_j \left(\frac{C_i}{X_i}\right)$, where *j* is the number of radionuclides.

Step 3: Compare the sum with 1 to make a decision on the exemption: $\sum_j \left(\frac{C_i}{X_i}\right) \leq 1$

If the above is correct, the material is exempt from the requirements of the Regulations.

Practical example No.2: A mineral has been both chemically and thermally processed, impurities have been removed and it is ready for shipment. The results of the radionuclides' analysis are as follows (nuclides in brackets assumed to be in equilibrium – see footnote (b) to the Table 1 of the Regulations):
Th chain: ^{232}Th=1.2 Bq/g, ^{228}Ra=1.0 Bq/g (~^{228}Ac=1.0), ^{228}Th=1.2 Bq/g (~^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb=1.2 Bq/g), ^{212}Bi=1.0 Bq/g (~^{208}Tl+^{212}Po=1.0 Bq/g);
U chain: ^{238}U=0.4 Bq/g (~^{234}Th, ^{234}Pa, ^{234}U=0.4 Bq/g), ^{230}Th=0.5 Bq/g, ^{226}Ra=0.6 Bq/g (~^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb=0.6 Bq/g), ^{210}Bi=0.5 Bq/g (~^{206}Tl+^{210}Po=0.5 Bq/g).
Calculations:
1. The ratios for thorium chain:
[1.2/100] (Th^{232}) + [1.0/100] x 2 (Ra^{228} & Ac^{228}) + [1.2/10] x 5 (Th^{228} & Ra^{224}, & Rn^{220} & Po^{216} & Pb^{212}) + [1.0/100] x2 (Bi^{212} & Tl^{208}+Po^{212}) = 0.652
2. The ratios for uranium chain:
[0.4/100] x 4 (U^{238} & Th^{234} & Pa^{234} & U^{234}) + [0.5/10] (Th^{230}) + [0.6/100] x 7 (Ra^{226} & Rn^{222} & Po^{218} & Pb^{214} & Bi^{214} & Po^{214} & Pb^{210}) + [0.5/100] x 2 (Bi^{210} & Tl^{206}+Po^{210}) = 0.118
3. The sum is = 0.770
4. The value of 0.77 is less than one; therefore the material is exempt from the Regulations.

2.2 (b) If the complete analysis of the material has not been carried out

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

Table 2 in para 406 of the Regulations 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 2 (*Activity concentration for exempt material*), which has three lines (associated activity concentration limits multiplied by the factor of 10 for 'natural material' are presented in the brackets):
Only beta or gamma emitting nuclides are known to be present (100 Bq/g)
Alpha emitting nuclides, but no neutron emitters, are known to be present (1 Bq/g)
Neutron emitting nuclides are known to be present or no relevant data are available (1 Bq/g)

[→]

As it would be very rare that a mineral to be transported has only beta and gamma emitting nuclides the value of 100 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 1 Bq/g will be applicable.

Practical example No.3: The same material as in the Practical example No.2 above is ready for shipment. The results of the radionuclides' analysis are not available, the only known value is the concentration of ^{232}Th = 1.2 Bq/g. In accordance with value specified in Table 2 in para 406, the material will not be exempt from Regulations.

A note on practical examples 2 and 3:
The costs 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'. The suggested approach is to use the partial data (2.2(b)) and, if it appears that a material is not exempt, – carry out the detailed analysis and use the method described in 2.2(a).
If the laboratory analysis shows that activity of the material to be transported is very close to the limit (above 9 Bq/g for a physically separated mineral concentrate, or the sum of activity concentrations calculated by the method described in 2.2(a) is above 0.9) – it would be prudent to take additional samples to ensure that at no time the limits are exceeded.

2.3. A note on uranium

Para 246 of the Code 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 nuclide mixture of the uranium chain may be disrupted but that the uranium nuclide mixture (^{238}U to ^{235}U ratio) is undisturbed (the uranium is not enriched in the ^{235}U isotope).

"U_{nat}" 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. Therefore, the mined materials that have not been subjected to any chemical or thermal processing of any kind may be considered as "U_{nat}". Additional information on this issue is presented in [5].

2.4. Procedure to follow

If it has been established that transport regulations apply, the following will be required:

1. The carrier must possess an appropriate licence to deal with radioactive material.
2. Three copies of the appropriate transport declaration must be prepared by a responsible person (typically – a radiation safety officer). Two copies must be given to the driver (one stays with the transporting company, another is given to 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 an appropriate regulatory authority.
3. Appropriate training must be provided to all workers involved in the transport, loading and unloading the material (paras 311-314 of the Regulations)
4. Appropriate placards should be placed on the vehicle (Section V, Part 'Marking, Labelling and Placarding' – paras 534-548 of the Regulations).

3. Determination of the classification of the material

If the activity of the material exceeds appropriate limits there is a need for a classification – to ensure that proper placards are displayed during the transport. Firstly, there is a need to determine the transport index and the category of the consignment.

3.1. Transport index (para 526):

(a) Determine the maximum radiation level 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 and SCO-I. The value determined shall be multiplied by 100 and the resulting number is the transport index.
(b) For tanks, freight containers and unpackaged LSA-I and SCO-I, the value determined in step (a) above shall be multiplied by the appropriate factor from Table 6.

Practical example No.4: Measured radiation level is 3 microSv/hour (0.003 millisieverts per hour) gives the transport index as 0.3. The values in Table 6 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 less than 20m^2), and the multiplication factor will be 3.
Therefore, if material is transported in a single truck, the transport index will be 0.9, if a large road train is used – the transport index will be 3.

[→?] – load being *measured* (2005) vs. load being *transported* (2000)

3.2. Category (para 533, Table 7):

The category of the load is determined based on the transport index and the radioation level on external surface. Please note the difference – transport index is determined by measuring radiation levels at a distance of 1 metre from the truck, for categorisation of the load the measurement on the surface is required.

- If the transport index is 0 and the surface radiation level is <5microSv/hour, the Category will be I-WHITE;
- If the transport index is more than 0 but less than 1, and the surface radiation level is more than 5 microSv/hour but less that 500 microSv/hour, the Category will be II-YELLOW;
- If the transport index is more than 1 but less than 10, and the surface radiation level is more than 500 microSv/hour but less that 2000 microSv/hour, the Category will be III-YELLOW;
- III-YELLOW category is also used if material is transported under 'special arrangement' (please refer to para 238 of the Regulations).

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

3.3. Specific Activity (para 226):

Para 226(a) of the Regulations – 'Low Specific Activity Material' gives the following definition of LSA-I:

LSA material shall be in one of three groups:
(a) LSA-I
(i) Uranium and thorium ores and concentrates of such ores, and other ores containing naturally occurring radionuclides which are intended to be processed for the use of these radionuclides;
…
iv) Other radioactive material in which the activity is distributed throughout and the estimated average specific activity does not exceed 30 times the values for activity concentration specified in paras 401–406, excluding fissile material in quantities not excepted under para 672.

[→]

Practical example No.5: If the activity of the material to be transported is less than 300 Bq/g, the marking "LSA-I" should be used on the transport label/placard. If, however, the value exceeds 300 Bq/g (which would be quite rare) – the marking "LSA-II" should be used.

4. Determination if the shipment can be transported as 'excepted package'

If the determined activity level of the material to be transported exceeds the limit of 10 Bq/g only by a low margin, there is a possibility that the load can be classified as *excepted* package (please note the difference with *exempted* package [activity less than 10 Bq/g], when Regulations do not apply at all).

The main criterion for the determination of the excepted package is in the para 516:
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.

Practical example No.6: If the material contains about 20 Bq/g of ^{232}Th a radiation level from its surface will be approximately 12 microSv/hour – the value can be measured or estimated using relevant dose coefficients [6].
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 microSv/hour, and the materials can be classified as excepted package.

All requirements of Regulations specified in 2.4 above must be complied with (licensing, training, declarations), except the last (placarding).

Para 518 gives 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.
Para 536 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.

[→]

Using the data provided in Table 8 of the Regulations, the conclusion can be made that in the case of minerals' transport as an excepted package the load/container will be marked only with 'UN2910' instead of the "radioactive" sign. This sign, however, will be required to be visible when, for example, the tarp is taken from the top of the truck or when a container is opened (the word "RADIOACTIVE" must be visible upon opening the package) – there are different technical ways to address this.

5. Placarding

Detailed data on marking, labelling and placarding of loads are provided in paras 534–548 of the Regulations. There are two important points on the placement of placards:

5.1. Location

Para 571 of the Regulations specify that:
Rail and road vehicles… 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.

Para 546.1 of the Advisory Material to the Regulations [2] provides an additional comment:
546.1. Placards, which are used on large freight containers and tanks (and also on road and rail vehicles; see para. 570) are designed in a way similar to the package labels… in order to clearly identify 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 only may be used on large freight containers and tanks, where the enlarged label also serves the function of a placard.

[→]

5.2. Definition of the vehicle

The definition of the vehicle, provided in para 247 of the Regulations should be taken into account prior to arranging the bulk 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) or railroad car or railway wagon. Each trailer shall be considered as a separate vehicle.

<u>*Practical example No.7*</u>*:* A road train (a truck with a semi-trailer) will need to have four signs: one each – at the front and at the back, and two on each side. A longer road train, however, (for example, a truck with two trailers) will require six signs (two more on the second trailer).
In the case of transporting radioactive material by rail in several carriages an additional advice from an appropriate regulatory authority on the quantity and location of placards should be sought prior to transport.

6. ‘Exclusive use’

Most materials in minerals industry are transported unpackaged. In this case, in accordance with para 523, material is typically transported in the conveyance under exclusive use. The definition is provided in para 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 is carried out in accordance with the directions of the consignor or consignee.

Further information is provided in para 221.1. of the Advisory Material to the Regulations [2]:
The special features of an ‘exclusive use’ shipment are, by definition, first, that a single consignor must make the shipment and must have, through arrangements with the carrier, sole use of the conveyance or large freight container; and, second, that all initial, intermediate and final loading and unloading of the consignment is carried out only in strict accordance with directions from the consignor or consignee.

Most of the material that is transported by the minerals industry would classify for ‘exclusive use’, as it is quite uncommon for a truck transporting mineral from ‘A’ to ‘B’ to deviate for a delivery of a product like 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 is under the ‘exclusive use’.

The main benefit of having a vehicle under the ‘exclusive use’ is the fact that internal surfaces will not need to undergo decontamination between journeys.

Paras 513 and 514 of the Regulations state:
513. Except as provided in para. 514, any conveyance, or equipment or part thereof which has become contaminated above the limits specified in para. 508 [surface contamination limits – please see part 9 of the paper below] *in the course of the transport of radioactive material, or which shows a radiation level in excess of 5 microSv/h at the surface, shall be decontaminated as soon as possible by a qualified person and shall not be re-used unless the non-fixed contamination does not exceed the limits specified in para. 508, and the radiation level resulting from the fixed contamination on surfaces after decontamination is less than 5 microSv/h at the surface.*
514. A freight container, tank, intermediate bulk container or conveyance dedicated to the transport of unpackaged radioactive material under exclusive use shall be excepted from the requirements of paras 509 and 513 solely with regard to its internal surfaces and only for as long as it remains under that specific exclusive use.

Further information is provided in para 513.1. and 514.1 of the Advisory Material to the Regulations [2]:
513.1. Conveyances may become contaminated during the carriage of radioactive material by the non-fixed contamination on the packages. If the conveyance has become contaminated above this level, it should be decontaminated to at least the appropriate limit. This provision does not apply to the internal surfaces of a conveyance provided that the conveyance remains dedicated to the transport of radioactive material or surface contaminated objects under exclusive use (see para. 514.1).
514.1. ...Decontamination of the internal surfaces after every use could lead to unnecessary exposure of workers….

7. Load cover

The earlier edition of the Regulations [3] contained a provision, allowing for loads of minerals to be transported without a cover; Schedule V, 2 (a) (i) of [3] stated that, –
LSA-I material may be transported unpackaged if:

All material other than ores containing only naturally occurring radionuclides are 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.
All Schedules have been deleted in the latest version of the Regulations [1] and relevant material distributed in appropriate paragraphs. This provision could not be located in [1] or [2], which confirms the common industry practice that in order to ensure that there is no escape of radioactive contents mineral that is being transported <u>needs</u> to be covered.

[→?] – clarify the need for covering the load

8. Mixing of different minerals in one conveyance for transport

There are two ways of blending/mixing the material:

a) Several different streams are simultaneously collected in one storage bin prior to transport and then loaded into a vehicle; and
b) The same several streams are loaded separately into a vehicle.

There is a definite problem with the method (b) above, which is described below.

There are no specific notes in Regulations explicitly prohibiting the practice. There are three main reasons for it not to be used, unless activity concentrations of blended materials do not differ more than by a factor of 10:

1. Impossibility of determining the specific activity of the material in accordance with para 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 (para 226 of the Regulations):
   226. Low specific activity (LSA) material shall mean radioactive material which 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.
   Para 226.4 of the Advisory Material [2] provides an additional clarification:
   226.4. The preamble also does not include wording relative to the essentially uniform distribution of the radionuclides throughout the LSA material. However, it states clearly that the material should be in such a form that an average specific activity can be meaningfully assigned to it. In considering actual materials shipped as LSA, it was decided that the degree of uniformity of the distribution should vary depending upon the LSA category.
   Paras 226.14 and 226.15 of the Advisory Material [2] offer an indication of what may be acceptable:
   226.14. A simple method for assessing the average 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. It is suggested that the differences in specific activity between portions of a factor of less than 10 would cause no concern.
   226.15. Judgement needs to be exercised in selecting the size of the portions to be assessed. The method described in para. 226.14 should not be used for volumes of material of less than 0.2 m^3. For a volume between 0.2 m^3 and 1.0 m^3, the volume should be divided into five, and for a volume greater than 1.0 m^3 into ten parts of approximately equivalent size.
   Therefore, 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.

3. The transport index of the load is determined by measuring of the maximum radiation level at 1 metre from the truck and categorisation is carried out by measuring of the maximum surface radiation level.

Practical example No.8: If 2 tonnes of monazite concentrate (specific activity of 90 Bq/g) are placed on the bottom of the trailer and then covered with 23 tonnes of the material with much lesser activity – for example sand processing tailings with specific activity of 1 or 2 Bq/g:

- The specific activity and class of the material cannot be determined by simple averaging, as 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 specific activity of the load can be calculated and it is also likely that the surface radiation level from a vehicle/container will be less than 5 microSv/hour. In this case, transporting of the mixed material as an 'excepted package' is possible.

There is also an uncertainty on how the surface radiation levels should actually be measured. In the absence of the contrary, one must assume that measurements should be done not only on the side surfaces, but also on the bottom and top of the load (please see part 4 above). In this case any options to transport any material with >10 Bq/g as 'excepted package' after some kind of blending in the truck are quite impractical.

Practical example No.9: 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 on the bottom of the trailer would not be required):
If we consider blending of monazite concentrate (90 Bq/g) with plant tails (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 and it does not touch the walls from the inside there is a possibility that this load would be an 'excepted package' (measurements will have to be carried out in any case). Basically, unless we have these 2-3 m^3 positioned directly in the middle of the load and it is separated from the walls from all sides – Regulations will apply. Even if this method is considered in theory – it will be next to 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, no matter how accurate the positioning and amount of the material in the middle of the trailer may be, the sand will undoubtedly move to at least one side of the trailer during the travel to another storage bin with 'less radioactive' material.

9. Surface contamination

A different issue is associated with the fact that there are no special provisions for 'natural material' in the Regulations in regards to surface contamination. In case of heavy mineral sands, for example, – if even a 0.5-mm thick layer of a sand concentrate is present on the surface of an item to be transported – it is likely to be classified as a 'Surface Contaminated Object'.
The only known provision for surface contamination originating from NORM appears to be in place in Nigerian legislation, where acceptable levels are set for both alpha, beta and gamma emitters at 80 Bq/100cm^2 for the average value and at 250 Bq/100cm^2 for the maximum value [7]. The limits for surfaces contaminated with TENORM (Technologically Enhanced NORM) are also provided in Suggested State Regulations in the USA [8].

9.1. Definitions

Para 214 of the Regulations and the associated part of the Advisory Material specify what 'surface contamination' is:
Regulations: *214. 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/cm^2 for all other alpha emitters.*

Advisory Material: *214.3. Any surface with levels of contamination lower than 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 Regulations. For instance, a non-radioactive solid object with levels of surface contamination lower than the above levels is out of the scope of the Regulations, and no requirement is applicable to its transport.*

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

There are two types of surface contaminated objects, which are defined in para 241 of the Regulations:
Surface contaminated object
241. Surface contaminated object (SCO) shall mean a solid object which is not itself radioactive but which has radioactive material distributed on its surfaces. SCO shall be in one of two groups:
(a) SCO-I: A solid object on which:

(i) the non-fixed contamination on the accessible surface averaged over 300 cm² (or the area of the surface if less than 300 cm²) does not exceed 4 Bq/cm² for beta and gamma emitters and low toxicity alpha emitters, or 0.4 Bq/cm² for all other alpha emitters; and

...
(b) SCO-II: A solid object on which either the fixed or non-fixed contamination on the surface exceeds the applicable limits specified for SCO-I in (a) above and on which:

(i) the non-fixed contamination on the accessible surface averaged over 300 cm² (or the area of the surface if less than 300 cm²) does not exceed 400 Bq/cm² for beta and gamma emitters and low toxicity alpha emitters, or 40 Bq/cm² for all other alpha emitters;

Para 523 of the Regulations details when surface contamination objects can be transported unpackaged:
523. 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 ten times the applicable level specified in para. 214; and
(c) For SCO-I where it is suspected that non-fixed contamination exists on inaccessible surfaces in excess of the values specified in para. 241(a)(i), measures shall be taken to ensure that the radioactive material is not released into the conveyance.

It is very unlikely that materials processed by minerals industry will contain alpha emitters that will not be classified as 'low toxicity' ones. The following limits are, therefore, applicable to any item transported from a mineral mining/processing site on a public road:

- Surface contamination is less than 0.4 Bq/cm² – an object is not classified as 'contaminated';
- Surface contamination is above 0.4 Bq/cm² but less than 4.0 Bq/cm² – an object will fall into an "SCO-I" category;
- Surface contamination is above 4 Bq/cm² (but not more than 400 Bq/cm²) – an object will fall into an "SCO-II" category.

Therefore, if any object is found to have surface contamination in excess of 0.4 Bq/cm² it will need to be transported in accordance with the requirements of the Regulations, as described in part 2.4 above. After the transport, a vehicle used for this purpose will need to be decontaminated – in accordance with para 504 of the Regulations:
504. Tanks and intermediate bulk containers 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/cm²

for beta and gamma emitters and low toxicity alpha emitters and 0.04 Bq/cm^2 for all other alpha emitters.

Please note that IAEA 2005 Regulations require that not only potentially contaminated objects but also the conveyance that is used to transport them should be checked for the presence of surface contamination in excess of specified limits.

9.2. Practical considerations

Potentially all equipment and buildings used in the processing of minerals containing naturally occurring radioactive material may become 'surface contaminated objects' and it is important to ensure that no contaminated equipment and 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 a simple surface contamination test can be 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 carried out. 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'. If, for example, it is desired that no objects will be classified as 'surface contaminated' in a load of scrap metal, this particular item will need to undergo additional cleaning prior to any tests for surface contamination.

Surface contamination measurements that typically follow the measurement of gamma radiation levels are quite easy to perform:

- 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 alpha and beta radiation;
- 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 (using the conversion factor for a particular monitor).

As specified in part 4 above, there is a possibility that surface contaminated items can be transported as 'excepted package' (definition from para 516 of the Regulations):

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

Additional requirements (described in the practical example 10 below) will need to be satisfied before the load can be transported as 'excepted package' – without a 'radioactive' sign on the outside of the conveyance (all other requirements of transport regulations specified in 2.4 above must be complied with - licensing, training, transport declarations).

<u>*Practical example No.10:*</u> Surface contaminated items need to be transported by road from a processing site to a mining site for the final disposal in a mined out pit. An average gamma-radiation level from items is 2.0 microGy/hour and surface contamination level is, on average, 0.8 Bq/cm^2.

- It is suggested that all material is to be wrapped in fine mesh shade cloth or covered to ensure that, –
  a) There will be no escape of radioactive contents from the conveyance nor will there be any loss of shielding (para 523(a));
  b) As contamination on the accessible and the inaccessible surfaces will not be greater than ten times the applicable level specified in para 214, there will be no need to have each conveyance under exclusive use (para 523(b));
  c) If it will be suspected that non-fixed contamination exists on inaccessible surfaces, measures will be taken to ensure that the radioactive material is not released into the conveyance (para 523(c));
- There will be no requirement for trucks to bear the signs 'Radioactive SCO-I', as the package will be classified as 'excepted' (para 516); and no contamination will be present of any accessible surface of the load;
- All drivers involved must undergo a specific radiation safety induction;
- Transport declarations must be prepared and truck will not be allowed to leave site until it has been established that all documentation is in order;
- Each truck should be surveyed to ensure that these conditions are strictly complied with.

A summary for different levels of surface contamination:

a) <0.4 Bq/cm^2 – exempted;
b) >0.4 but <4.0 Bq/cm^2 (covered/wrapped) – excepted: all documents, no placarding;
c) > 0.4 but <4.0 Bq/cm^2 (open vehicle) – not excepted: all documents, 'SCO-I' placard;
d) >4.0 Bq/cm^2 – all documents, 'SCO-II' placard.

Further information on issues associated with surface contamination and a detailed technical advice can be found in IAEA TECDOC-1449 [9].

This paper is the first part of the discussion on the subject of transport of Naturally Occurring Radioactive Material. The second part, entitled 'Regulation of Natural Radioactivity in International Transport and Trade' was presented at the Second Asian and Oceanic Congress on Radiological Protection in October 2006 in Beijing; and both papers are available on the Internet [10].

REFERENCES

1. Regulations for the Safe Transport of Radioactive Material, Safety Requirements No. TS-R-1, International Atomic Energy Agency (IAEA), Vienna, 2005 Edition
2. Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, Safety Guide No. TS-G-1.1, International Atomic Energy Agency (IAEA), Vienna, 2002
3. Regulations for the Safe Transport of Radioactive Material, Safety Requirements No. TS-R-1, International Atomic Energy Agency (IAEA), Vienna, 1996 Edition (Revised in 2000)
4. Code of Practice – Safe Transport of Radioactive Material, Radiation Protection Series No.2, Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2001
5. P. Burns, P. Crouch. Exemption Levels for Transport of Ores and Concentrates Containing Uranium and Thorium, Radiation Protection in Australasia, Vol.23, No.1, May 2006, pp.12-14
6. UNSCEAR 2000 Report to the UN General Assembly, Sources and Effects of Ionizing Radiation, Volume I - Sources , Annex B – Exposures from Natural Radiation Sources, p.116
7. I. Funtua, Regulatory and Management Approach for TENORM in Nigeria, IAEA TECDOC-1484, Regulatory and management approaches for the control of environmental residues containing naturally occurring radioactive material (NORM), Proceedings of a technical meeting held in Vienna, 6–10 December 2004, IAEA, 2006
8. Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM), Part N of the Suggested State Regulations for Control of Radiation, Conference of Radiation Control Program Directors, Inc, 2004, http://crcpd.org/
9. IAEA TECDOC-1449, Radiological Aspects of Non-fixed Contamination of Packages and Conveyances, International Atomic Energy Agency (IAEA), Vienna, 2005
10. Internet site http://www.calytrix.biz/radlinks/tenorm/