REFERENCE NOTE ON THE TRANSPORT OF NORM, BASED on IAEA SSR-6 (2018)
Version 5.1 – August 2019

This reference note contains information that can be used to correctly estimate the applicability of the IAEA Transport Regulations to NORM, to establish clearance levels for surface contaminated items and to interpret regulations and guidelines in regards to the signposting requirements for bulk mineral shipments.

This document was developed for the minerals industry and for the competent authorities – it should be borne in mind that there is no 100% guarantee that all information is absolutely correct. The first version of the document was developed in October 2016 and distributed for comments to 92 industry and regulatory stakeholders in 36 countries; the second version incorporated all received comments.

This version 5 has been specifically amended to ensure that both this document and the associated 'excel calculator' are in full compliance with the latest version of the IAEA SSR-6 on the Transport of Radioactive Materials. The error in the interpretation of ^{235}*U values has been corrected and the excel calculator – modified to fit the computer screen.*

It is important to note that there are several inaccuracies in the Western Australian Guideline on the transport on NORM (2010) and its use for the determination of the applicability of the regulations is not recommended, especially for the materials where uranium and thorium decay chains may not be in secular equilibrium.

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PART 1 – GENERAL CONSIDERATIONS

In many cases there is an insufficient level of communication in regards to the legal requirements between the exporter and importer of a mineral concentrate containing NORM and the relevant Competent Authorities. The lack of communications between logistics companies and government departments in different countries (and States within one country), combined with 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 (issued by the IAEA) are not adopted simultaneously across the world, and different requirements may apply in different jurisdictions.

It is essential that any mineral processing company and relevant logistics operators carefully examine all applicable legislation, to fully understand how radioactive material is defined within the respective jurisdictions through which NORM is proposed to be transported, so as to be absolutely clear about which controls will apply to a specific material.

Definition of naturally occurring radioactive material (NORM) is given in the IAEA Safety Glossary 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.*

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

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

1.1. Material on a mining/processing site

If the materials are transported 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 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 IAEA Regulations must be complied with.

1.2. Different modes of transport

In 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 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 – 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 approximately an hour, 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 inhalation would also need to be considered, and in case of a marine shipment, the same considerations for radon (as above) will apply to opening a ship's hull at a destination port.

1.3. Differences between 'natural uranium' and uranium (natural)

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

§247 of the Regulations 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(natural)" 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(natural)".
This same argument applies to thorium ores, which have not been chemically- or thermally-processed and are classified as Th(natural).

PART 2 – CORRECT CALCULATIONS

2.1. Definitions

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 to activity concentrations only, not to the 'total activity of the consignment'.

The next step is to determine if material to be transported is in the scope of the Regulations. In accordance with §236 of the IAEA SSR-6 –
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 natural thorium is to be transported, two limits will apply to its shipment:

- Activity concentration limit for exempt material, 10 Bq/g for natural thorium, and
- Activity limit for an exempt consignment, 1,000 Bq for natural thorium (the '10-times' 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 does need to be signposted or labelled.
The above consideration is particularly important for transporting small mineral samples to analytical laboratories.

2.2. Two different types of materials requiring different calculation methods

Uranium and thorium 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 or ilmenite sand, or 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 minerals, 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 250-300^{o}C is suggested as a general guide at which additional analysis of the material may be required.

2.3. NORM in secular equilibrium

If thorium and uranium decay chains is 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(natural) and U(natural) concentrations are used in the calculations, as follows:

$$C\left({}^{Bq}/_{g}\right) = \frac{Th\,(ppm)\times 4.055 + U(ppm)\times 12.384}{1000}$$

If the result is less than 10 – the material is not classified as radioactive for transport.
It is important to note that typically the laboratories 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 ThO_2 equals to 0.879 ppm of Th
- 1 ppm of U_3O_8 equals to 0.848 ppm of U

2.4. Transport of other NORM

In some circumstances the concentrations of the radionuclides that are not part of ^{232}Th, ^{238}U and ^{235}U decay chains may also needs 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 of the naturally occurring radionuclides such as ^{40}K and ^{87}Rb may be relatively high and needs to be considered before transport.

The limiting concentrations in the SSR-6 are as follows:

- ^{40}K – 100 Bq/g (1000 Bq/g for NORM), and
- ^{87}Rb – 10,000 Bq/g (100,000 Bq/g for NORM).

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 small fracton of total potassium and rubidium are radioactive isotopes.

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.

The following coefficients must be used for the correct application of the equation above:

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

It is important to note that it is extremely unlikely that NORM containing only potassium and rubidium will be subject to the transport safety regulations and the infrormation is provided for information only, for very rare cases when K-40 and Rb-87 also need to be considered in the fractions equation (part 2.5 below), alongside radionuclides from thorium and uranium decay chains.

2.5. NORM not in secular equilibrium

For many materials and mineral concentrates the analysis of only uranium and thorium is not sufficient.

> Note 1: The calculations for the materials where the radionuclides in thorium and uranium decay chains are not in secular equilibrium are incorrect in the Western Australian 2010 guideline. 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 SSR-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.*
>
> Note 2: The 'fractures' equation from the §405 of the Regulations applies to the materials where the decay chains are not in secular equilibrium. §I.88 in the SSG-26 (advisory material to the Regulations) repeats this equation, but §I.87 of the SSG-26 contains the old calculation method – which is much simpler to use. The same results are achieved when using one or another method of the calculation – the excel file that is accompanying this document contains the instructions on the use of both methods.

The following steps are suggested for the accurate estimation of the applicability of the Regulations to the transport of NORM.

1. If both the producer/transporter and the Competent Authority are certain that ^{238}U and ^{232}Th are in equilibrium, the analysis is to be performed just for U and Th.
2. 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:
   - ^{232}Th decay chain: ^{232}Th, ^{228}Ra, ^{228}Th;
   - ^{238}U decay chain: ^{238}U, ^{234}U (no analysis, it is assumed to be equal to ^{238}U), ^{230}Th, ^{226}Ra, ^{210}Pb;
   - ^{235}U decay chain: Not required.

- If it is confirmed that both ^{232}Th and ^{238}U decay chains are in equilibrium – return to step 1 for all subsequent analyses (part 2.3 above, just U and Th);
- If the disequilibrium is confirmed – proceed to step 3.

3. Analyse for the following radionuclides to determine the applicability of SSR-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 Competent Authority: ^{235}U, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Ra.

The footnote (b) to the Table 2 of the SSR-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 – which is not correct for NORM, in many circumstances: in the processing of minerals radium and lead/polonium would 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 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 3 in this part), the measurements of the concentrations of seven radionuclides (step 2 in this part) should be carried out to assess the secular equilibrium of the decay chains.
(b) The regular analysis for all radionuclides (i.e. for each shipment) should not be required – the sampling will only need to be repeated if the feedstock changes, the processing method changes, of both of those change.

2.6. Calculations

The equation that is given in the Regulations, and further explained in the excel file is:

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

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***
X_m is the derived value of activity concentration limit for exempt material

Calculation method and *example* for the material in secular equilibrium, containing 1500 ppm (6.08 Bq/g) of thorium and 50 ppm (0.62 Bq/g) of uranium is presented below:

Step 1. Sum the activity concentrations in the mixture for all radionuclides nuclides to obtain the total activity concentration in the mixture:

6.08 + 0.62 = 6.70 Bq/g

Step 2. For each nuclide ***i*** divide the activity concentration, measured for that nuclide, by the sum in Step 1 above, to obtain the fraction of the nuclide ***i*** in the mixture:

*Thorium **f(i)** : 6.08/6.70 = 0.91*
*Uranium **f(i)** : 0.62/6.70 = 0.09*

Step 3. Divide the ***f(i)*** derived above, by the ***X(i)*** – the appropriate limit for this radionuclide from Table 2 of the Regulations (multiplied by the factor of 10 as allowed by for natural materials):

*Thorium **f(i)/X(i)** = 0.91/10 = 0.091*
*Uranium **f(i)/X(i)** = 0.09/10 = 0.009*

Step 4. Calculate the X_m value for this particular mixture:

X_m *= 1 / (0.091+0.009) = 10 Bq/g*

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

6.70 Bq/g < 10 Bq/g – the material is not classified as 'radioactive' for transport.

The examples of the calculations for the non-equilibrium situations are much more complex and it is suggested that the reader studies the Excel 'calculator' file accompanying this document.

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

The analysis of the material for the nuclides of ^{235}U 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 3 of part 2.5 above) the analysis will be required for the following radionuclides: ^{235}U, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Ra.

The previous version of the note 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 238U 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%. Therefore, if there is a need to theoretically estimate the activity concentration of ^{235}U, the activity concentration of ^{238}U needs to be multiplied by 0.047, not by 0.01.

2.8. Materials with no ^{232}Th or ^{238}U, 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 to be transported, the examples are:

(a) Waste/sludge 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 inside 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 rather significant concentrations.

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

The examples of the calculations for all three cases above are given below.

Case (a): Assumed to be 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 in 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 (multiplied by the factor of 10 as allowed by for natural materials): $^{226}Ra = 0.0050$, $^{210}Pb = 0.0028$, $^{210}Po = 0.0022$.
Step 4. Calculate the X_m value for this particular mixture: $X_m = 100$ *Bq/g*
Step 5. Compare the calculated X_m value with the measured total activity concentration, calculated in step 1: 180 *Bq/g > 100 Bq/g – the material is classified as 'radioactive' for transport.*

Case (b): Assumed to be 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 (~2 months), no ingrowth of ^{210}Po in concentrations requiring assessment has taken place and the material in the drum 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 ^{210}Pb are used in the assessment:

- The activity concentration limiting value is 100 Bq/g, taking into account that the material is 'natural',
- The activity limit for the exempt consignment is 100,000 Bq.

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
- 2,100,000 Bq > 100,000 Bq.

However, as the gamma radiation level from the package is expected to be low, and, say, was measured to be at 2 microSv/hour – the box can be transported as an *excepted* package, without radiation labels or placards on the outside surfaces (please see part 2.9 below for more details).

Case (c): Assumed to be a 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 in 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 (multiplied by the factor of 10 as allowed by for natural materials): $^{210}Pb = 0.0075$, $^{210}Po = 0.0025$.
Step 4. Calculate the X_m value for this particular mixture: $X_m = 100$ *Bq/g*
Step 5. Compare the calculated X_m value with the measured total activity concentration, calculated in step 1: 160 *Bq/g > 100 Bq/g – the material is classified as 'radioactive' for transport.*

2.9. Additional justification for the analysis for radionuclides other than U and Th

The comparison of the levels given in Table 2 of the SSR-6 with the 'default' values provided in Table 3 clearly illustrates the need for the additional analyses of minerals, where a 'non-equilibrium' situation may exist.

SSR-6 Table 2 provides values for individual radionuclides and it is relatively easy to use the equation above and the Excel 'calculator', which are in the range between 10 and 1000 Bq/g for natural radionuclides.

SSR-6 Table 3 provides "basic radionuclide values for unknown radionuclides or mixtures", where the value for "alpha emitting nuclides, but no neutron emitters are known to be present" is given at 0.1 Bq/g; plus the '10-times' factor for NORM only applies to the radionuclides listed in Table 2.

As almost all NORM would contain some alpha emitting radionuclides – the limiting concentration will be 0.1 Bq/g – 100 or 10000 times less than the limit that will be applicable in the case when the data on the concentrations is available.

For example, a material that is known not to be in secular equilibrium, such as bauxite concentrate or synthetic rutile – containing more than 25 ppm of thorium (and thus not subject to any other radiation safety regulation), will need to be placarded as 'radioactive' for transport. But, if the same material contains around 2,000 ppm of thorium and the data for other radionuclides is available (and their concentrations are less than thorium one) – the material may not need to be placarded as 'radioactive'.

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.

§515 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 given in Figure 2 (reproduction of the Figure 7 of the Regulations)

Using the data provided in Table 1 of the Regulations, the conclusion can be made that 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.

This sign, similar to the one given in Figure 2 (reproduced from the Figure 6 of the Regulations 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).

PART 3 – SIGNPOSTING/PLACARDING

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

3.1. Determination of the Transport Index (TI)

In accordance with §523 of SSR-6, the measurement of gamma radiation level from the surface is undertaken at a distance of 1 metre. The result in milliSieverts per hour is multiplied by 100 and the result is the TI value.
If the result of a measurement is 2 microSv/h at a distance of 1 metre from the truck with mineral, the TI is calculated as follows:
2 microSv/h = 0.002 mSv/h → therefore the TI = 0.2

In minerals industry the materials are almost always transported in bulk – it is, therefore, essential to use the multiplication factor for unpackaged LSA-I and SCO-I given in Table 7 of the SSR-6. The multiplication factors are given for "largest cross-sectional area of the load being measured" and vary from 1 to 10.
If the same material as in the example above is transported in one 2-tonne bulka bag, the cross-section will be between 1 and 5 m^2, the factor is 2 and the TI value will be 0.4. If the same material is transported in bulk in the large truck, the cross-section will be more than 20 m^2, multiplication factor will be 10 and, thus, the TI value will be 2.

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 / package. 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.

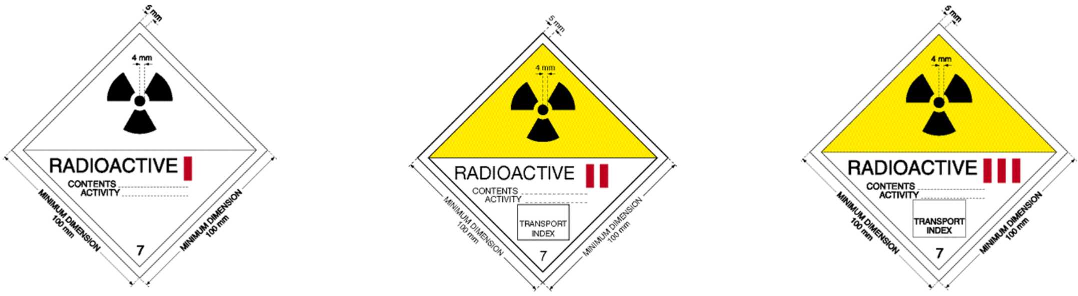
3.2. Determination of the correct transport label

In accordance with §529 and Table 8 of the Regulations, the measurement of gamma radiation level is undertaken at the surface.

(a) If TI is not more than 0.05, and the surface radiation level is below 5 microSv/hour, the category of the label will be I-WHITE.
(b) If TI is more than 0 but less than 1, and the surface radiation level is above 5 microSv/h, but below 500 microSv/h, the category of the label will be II-YELLOW.
(c) If TI if more than 1 but less than 10, and the surface radiation level is more that 500 microSv/h, the category of the label will be III-YELLOW.

The illustrations for the labels are provided below, in Figure 1.

Figure 1. Transport labels – reproduced from Figures 2, 3 and 4 of the IAEA Regulations



It is highly unlikely that surface gamma radiation levels measured from naturally occurring radioactive materials will exceed 300-350 microSv/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):
Where the TI satisfies the condition for one category but the surface radiation level satisfies the condition for a different category, the package, overpack or freight container shall be assigned to the higher category.

§529 of SSR-6 needs to be considered together with §523, 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 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 never be as high as the default values.

The bulk "unpackaged" materials in the minerals industry may only be transported under the *exclusive use* arrangement, as per §520(b) of the Regulations:
LSA material and SCO in groups LSA-I and SCO-I 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.

The main advantage of that arrangement is that, in accordance with §514 of the Regulations, 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 and 567 if the value of Transport Index (TI) exceeds 10, it can only be transported under the exclusive use arrangement.

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

In accordance with §409 of The Regulations most materials transported by 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.

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.

Please note that contrary to the 2010 Western Australian guideline for transport of NORM, "10-times multiplication factor for natural materials" <u>does not apply</u> in addition to the '30-times' factor, given in §409(a)(iv).

It is also important to note that the '30-times' factor from §409(a)(iv) applies only to individual radioisotopes, such as ^{226}Ra, ^{210}Pb, etc.
For example, taking into account that the limiting value for ^{226}Ra in the Table 2 of the Regulations is 10 Bq/g –

The scale containing 290 Bq/g of ^{226}Ra will be classified as LSA-I, but

If ^{226}Ra concentration is 320 Bq/g – it will be classified as LSA-II; therefore additional safety measures will need to be taken in the process of its transport.

3.4. Determination of what information needs to be on the transport label

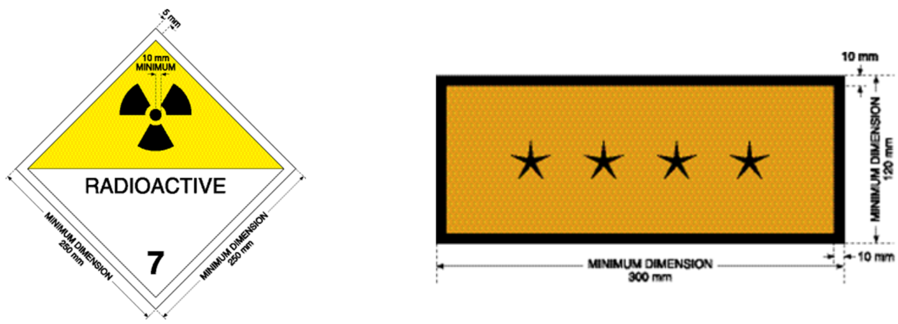
There appear to be many misinterpretations of signposting requirements, especially in the transport of NORM materials in bulk using road transport – and particularly in regards to the use of UN numbers and selection of correct information for the transport labels:

- The LABELS are illustrated in Figure 1 and they are small in size, 10x10 cm.
- The PLACARD is illustrated in Figure 2 and it is large, 25x25 cm.

The §543 says (with added highlight):
543. Large freight containers carrying packages other than excepted packages, and tanks shall bear <u>four</u> 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 Figs 2–4, except having the minimum size shown in Fig. 6.

Figure 2. Transport placards – reproduced from Figures 6 and 7 of the IAEA Regulations



Therefore:

- If there are several packages with radioactive material in the vehicle (for example, in the one that is transporting radioactive isotopes between hospitals) – each of the packages is LABELLED, and the vehicle itself is PLACARDED.
- Full compliance with the Regulations requires placing both labels and placards on the vehicles – but there is a provision in §543 that instead of putting those side-by-side, the LABEL is enlarged to 25x25cm size and is used instead of a PLACARD – on all four sides of the vehicle.

The note to the Figure 2 (Figure 6 in the Regulations) illustrating the PLACARD says –
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.

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.

Therefore –

If the vehicle is used to transport isotopes between hospitals in type A containers:

- Each container is LABELLED as per Figure 1 – as required;
- The vehicle itself is PLACARDED as per Figure 2 – the word "RADIOACTIVE" may be replaced with "UN2915" or "UN3332', as needed.

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

a. Each package is LABELLED as per Figure 1 – as required;
b. The vehicle itself is PLACARDED as per Figure 6 – the word "RADIOACTIVE" may be replaced with "UN2913".

If the vehicle is used to transport bulk NORM mineral:

Option 1:

(a) The enlarged LABEL is placed on it as required;

(b) The word "RADIOACTIVE" may not be replaced with "UN2912";

(c) On the LABEL the contents may be simply "LSA-I", as per §540(a)(ii) – if the material is classified as such;

(d) If material is classified as LSA-II, the data on the radioisitope(s) is required;

(e) 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.

Option 2:

- Both LABELS and PLACARDS are placed on the vehicle as required;
- The word "RADIOACTIVE" on the PLACARD may be replaced by "UN2912";
- The word "RADIOACTIVE" may not be replaced by "UN2912" on smaller LABELS; they will also need to contain the information on the contents of the material and the Transport Index.

PART 4 – SURFACE CONTAMINATION AND RELEASE OF ITEMS FROM SITES

All measurements described below need to be carried out in a 'clean' area. Measuring gamma radiation level from a possibly contaminated item in the vicinity of a mineral stockpile or at the wall of a processing plant will almost certainly provide a false reading, as the radiation levels measured from an item in a radiologically contaminated area will reflect an overall radiation level in this area, not the levels from the particular item.

It is acknowledged that establishing an area with a low natural background levels may not be always possible, especially in cases of small processing plants and laboratories – it is, however, recommended that such an area is designated at each site, as far as it is practicable.

The following factors also need to be considered, as they will influence the results obtained by the surveys for surface contamination:

- The size of the probe,
- The efficiency of the probe,
- The distance of measurement,
- The speed of measurement, and
- The geometry of measured objects.

The calibration certificate for the surface contamination probe should include:

4. A conversion factor between cps/cpm values, obtained by the monitor, and the value in Bq/cm^2, and
5. The efficiency of the probe for several radionuclides (both alpha- and beta-emitters, typical examples are ^{239}Pu, ^{238}U, ^{32}P, ^{137}Cs, ^{147}Pm, ^{60}Co and ^{90}Sr).

4.1. Gamma-radiation – simple

At the initial step the items need to be surveyed for gamma-radiation levels – which is easy to do and interpret. An item could be considered as possibly suitable for recycling if gamma radiation levels measured at some distance from it (say at 30-40 centimetres) are the same as the natural background in the area (in some cases the survey of gamma radiation levels may need to be carried out at shorter distances, of about 10 centimetres). It should be borne in mind that some radionuclides, such as ^{210}Pb, may not be detectable when gamma-radiation monitoring equipment is used – therefore, it is also essential to measure the levels of alpha- and beta- surface contamination, as described below.

It is also important to consider that the vast majority of factories and yards that handle and otherwise deal with scrap metal have a specific portal detectors installed at the entrances. If an item exhibiting higher than usual levels of gamma radiation is detected at the entrance – in most situations the whole shipment will be rejected.

Additional consideration is associated with the fact that, despite being cleared from any form of radiation control and management, the items may still be rejected by a recycling facility – simply because of their origin (such as, for example, a uranium processing plant). In these cases, a detailed guideline would need to be provided by an appropriate authority – to demonstrate that the items can be legally recycled/melted.

4.2. Surface contamination – complex and often misinterpreted

The IAEA Regulations provide the definition for 'surface contamination' and 'low toxicity alpha emitters':

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.

227. 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 physical and chemical concentrates; or alpha emitters with a half-life of less than 10 days.

Additional information is provided in the IAEA Safety Guide (SSG-26) issued in the support of the Regulations:

214.3. Any surface with levels of contamination lower than 0.4 Bq/cm^2 for beta and gamma emitters and for low toxicity alpha emitters, or 0.04 Bq/cm^2 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.

Therefore, when the level of surface contamination exceeds 0.4 Bq/cm^2 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 **<u>not</u>** classified as a 'low toxicity' alpha emitter and whilst the limit of 0.4 Bq/cm^2 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/cm^2 would be applicable for the classification of surface contaminated objects.

There always will be alpha emitting isotopes present in surface contamination in uranium industry. 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 ^{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 0.04 Bq/cm^2 is the one where the vehicles may need to be signposted as carrying surface contaminated objects, SCO-I. This level applies unless it is known that the material on the surface does not contain a significant proportion of ^{226}Ra, in which cases the signposting is needed at levels above 0.4 Bq/cm^2.

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 there are different values for *non-fixed* and *fixed* surface contamination. In mining and mineral processing (not in 'nuclear' applications) all surface contamination is usually considered to be "non-fixed", since it can be removed in any case, 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/cm^2, and §413(b)(i) – that SCO-II is any object with the levels up to 400 Bq/cm^2. SCO-III that will be introduced in the new 2018 Regulations is not considered in this discussion.

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 (^{226}Ra excluded):

- < 0.4 Bq/cm^2 – not contaminated, no signposting of any kind required;
- > 0.4 Bq/cm^2, but < 4 Bq/cm^2 – SCO-I signposting required;
- > 4 Bq/cm^2, but < 400 Bq/cm^2 – SCO-II signposting required;
- > 400 Bq/cm^2 – one would not be allowed to transport these items, but values of this kind are 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.

However, it is important to also note that the definition for non-fixed contamination in the IAEA 2007 Safety Glossary is: *"Contamination that can be removed from a surface during routine conditions of transport"*.

It is, therefore, recommended to ensure that all potentially contaminated objects are cleaned up prior to their transport, to ensure that no residual contamination can be accidentally removed 'during the routine conditions of transport'.
In these cases, different limits will apply, in accordance with §413(a)(ii): 40,000 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, and 4,000 Bq/cm^2 for all other alpha emitters – the levels of this magnitude are not expected in mining and mineral processing industry.

Other practical notes in regards to controls required in the process of transporting surface contaminated items:

There are three more paragraphs in the IAEA Regulations 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:*

- *4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters;*
- *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 this §508 for the levels on the *outside* surfaces of these 'packages' shall not be exceeded.

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

- *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.*
- *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.*
- *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.*

Effectively, 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 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 used 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.*

This paragraph 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.

In case of processing uranium ore, the following conclusion is based on alpha surface contamination levels, as:

- Unprocessed ore and concentrates: in the uranium chain, there are 8 alpha emitters and 6 beta emitters, so measuring and ensuring that alpha emitters meet the surface contamination limits would also make sure that the short-lived beta emitters do not exceed the surface contamination levels.
- Freshly extracted uranium, there are obviously more alpha emitters – as it will contain alpha-emitting isotopes, ^{238}U, ^{234}U and ^{235}U.
- Tailings with ^{238}U and ^{234}U removed – leaving 6 alpha emitters and 6 beta emitters, so, as in the case (a) above, measuring only alpha surface contamination levels would be sufficient.

4.3. The summary for the surface contaminated objects

Taking all of the above into consideration, the general suggestion is to have five types of surface contaminated objects, based on alpha surface contamination – which are simple to differentiate from each other:

(a) Less than 0.04 Bq/cm^2 – clean, can go anywhere for any purpose;
(b) More than 0.04 Bq/cm^2, but less than 0.4 Bq/cm^2 – not contaminated, can be transported unpackaged and not signposted, the only restriction is the release of objects to the general public;
(c) More than 0.4 Bq/cm^2, but less than 4 Bq/cm^2 – surface contaminated object class SCO-I, signposting and transport declaration required;
(d) More than 4 Bq/cm^2, but less than 400 Bq/cm^2 – surface contaminated object class SCO-II, control measures, signposting and transport declaration required;
(e) More than 400 Bq/cm^2 – typically not allowed to be transported, attempts need to be made to clean the surface and the regulatory authority should be contacted for the advice.