A DISCUSSION ON THE INTERPRETATION OF THE INTERNATIONAL ATOMIC ENERGY AGENCY REGULATIONS FOR THE TRANSPORT OF NORM ASSOCIATED WITH THE SOUTH AFRICAN MINING INDUSTRY

P.J.HINRICHSEN (Bsc Hons)
SENIOR RADIATION PROTECTION SPECIALIST
NATIONAL NUCLEAR REGULATOR, SOUTH AFRICA

1.0 INTRODUCTION

South Africa has an extensive mining industry, with total mineral sales in 2002 being R140 billion and total mineral exports being R110 billion. In this same year, the industry employed over 400 000 workers.

2.0 SCOPE

When the International Atomic Energy Agency Regulations for the Safe Transport of Radioactive Material (TS-R-1 [ST-1 Revised]) (the Regulations), was adopted by the regulatory body, the National Nuclear Regulator (NNR), in June 2001, the Industry requested the drafting of a guide on the interpretation of these regulations for NORM. This paper has arisen from the drafting of such a guide, drafted with the end-user in mind, giving an interpretation of the application of the Regulations to NORM. The paper is more “Qualitative” than “Quantitative” and raises a number of “peculiar” aspects of the application of the Regulations to NORM.

3.0 DEFINITION OF RADIOACTIVE MATERIAL

The definition of “radioactive material”, given in paragraph 236 of the Regulations, is as follows;

“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 paragraphs 401 – 406”

The key phrase in this definition is;

BOTH the activity concentration **AND** the total activity in the consignment.

Hence, to be exempt from the Regulations it is not necessary that BOTH the activity concentration limit AND the total activity limit be satisfied. As long as one of these limits is not exceeded the material is exempt from the Regulations.

The Regulations therefore give nuclide specific exemption values as opposed to the 1985 Edition of the Transport Regulations, which defined radioactive material as any material with a specific activity greater than 70 Bq g^{-1} irrespective of the radionuclides present within the material.

4.0 EXEMPTION CRITERIA

Paragraph 107 of the Regulations deals with instances where the Regulations do not apply. It explains the exemption criteria i.e. the conditions required for material not to be covered by the scope of the Regulations. In this paragraph the following statement is of significance to the mining and minerals processing industry.

Paragraph107 (e) states:

“The Regulations do not apply to natural materials and ores containing naturally occurring radionuclides which are not intended to be processed for the use of these radionuclides provided the activity concentration of the material does not exceed 10 times the values specified in paragraphs 401-406.”

For clarification on this point we turn to paragraph 107.4 of reference [3] .

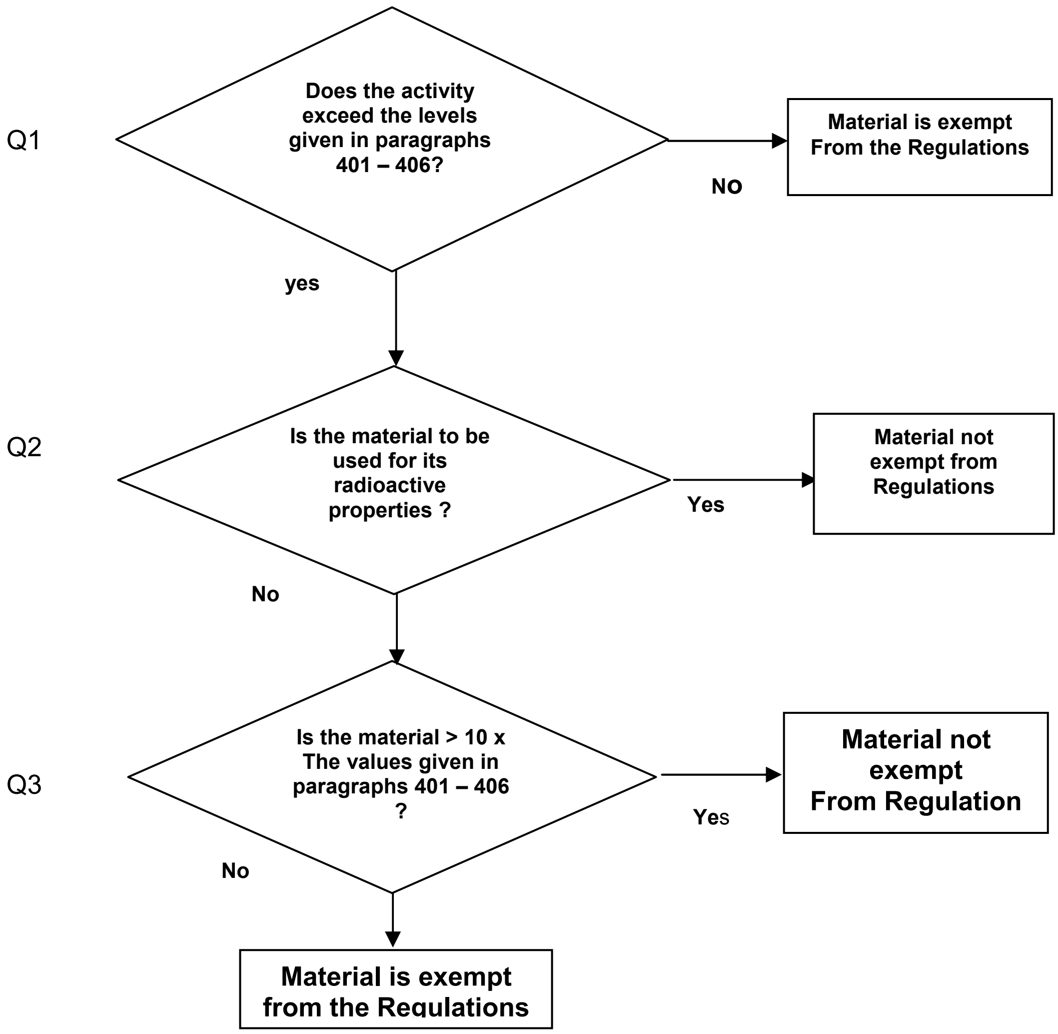
“107.4. The scope of the Regulations includes consideration of those natural materials or ores which form part of the nuclear fuel cycle or which will be processed in order to use their radioactive properties. The Regulations do not apply to other ores which may contain naturally occurring radionuclides, but whose usefulness does not lie in the fissile, fertile or radioactive properties of those nuclides, provided that the activity concentration does not exceed 10 times the exempt activity concentration values.

In addition, the Regulations do not apply to natural material and ores containing naturally occurring radionuclides which have been processed (up to 10 times the exempt activity concentration values) where the physical and/or chemical processing was not for the purpose of extracting radionuclides, e.g. washed sands and tailings from alumina refining. Were this not the case, the Regulations would have to be applied to enormous quantities of material that present a very low hazard..………………………….”

Hence there are ores where the activity concentration is much higher than the exemption values as given in Table I. Regular transport of these ores may be of radiological concern and a factor of 10 above the exemption values was chosen as a compromise between the radiological protection concerns and the practical inconvenience of transporting large quantities of material of low activity concentrations.

The correctness of this factor of 10 has been questioned by the NNR, as well as by a number of other national regulators. The questioning arises from the fact that there is apparently no radiological basis for choosing “10” as the factor. These concerns have been addressed through an IAEA Co-ordinated Research Project in which the NNR was a participant.

Hence, in determining whether or not a particular consignment is exempt from the Regulation the following decision tree must be followed;



In proceeding through the above decision tree compliance with the appropriate limit must be established at both Q1 and Q3. For the case of single nuclides this is as simple as looking at the limits given in paragraphs 401 – 406. However, since NORM contains mixtures of radionuclides, the process of comparison against the limit comes down to solving the mixture equations as discussed in Section 8.0 of this Paper.

4.1 Exemption Criteria and the Basic Safety Standards

The exemption values, for transport scenarios, are the same exemption levels for radionuclides as set out in Schedule 1 of the Basic Safety Standards (BSS). Hence, any material which is considered none-exempt from the requirements of the BSS is also declared none-exempt from the requirements of the IAEA Transport Regulations, bearing in mind the additional complication of the factor of 10, as described in paragraph 107 (e).

5.0 DEFINITION OF “NATURAL URANIUM” AND “U-$_{nat}$”

The Regulations contain references to both “Natural Uranium” and to “U-nat”. These two entities are not the same and it is essential that there is an understanding of their meaning and of when to apply them.

5.1 Definition of “Natural Uranium”

Paragraph 246 of the Regulations contains the following definition of “Natural Uranium”

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

Note that the definition above talks about “chemically-separated uranium”, which means that the nuclide mixture of the uranium series nuclides may in fact be disturbed from its natural state but that the uranium nuclide mixture (U-238 to U-235 ratio) is undisturbed (e.g. the uranium is not enriched in the U-235 isotope).

5.1 Definition of “Unat”

In the IAEA Basic Safety Standards and the IAEA Transport Regulations U_{nat} is not the same as “natural uranium”. While “natural uranium” refers to non-enriched but possibly chemically separated uranium, U_{nat} refers to chemically undisturbed uranium in secular equilibrium with all its daughters.

Hence an interpretation of this, relevant to NORM, is that ores taken straight from the earth, having not undergone any chemical, or other processing, of any kind, may be considered as “U-nat”.

Table 1 of the regulations hence contains limiting values relevant to U_{nat} but not to “natural uranium”. For deriving the relevant limits for natural uranium the particular NORM must be analysed for its radioactive content, and then the mixtures equations used to determine compliance.

6.0 DERIVATION OF THE A_1 AND A_2 AND OTHER LIMITING VALUES FOR RADIONUCLIDES.

Historically the A_1 and A_2 values given in the Regulations have been derived using the “Q-system” as it is known. It is beyond the scope of this paper to give a complete explanation of the Q-system, suffice it to say that Appendix 1 of reference [5] carries a detailed historical and factual explanation of the Q-system.

What must be understood however, is the division of a given nuclide decay chain into;

- progeny having a half life of 10 days or less, and
- progeny having a half-life exceeding 10 days.

On this point, the Q-system assumes that the maximum transport time for a shipment would be 50 days. Hence it is assumed that, in a given decay chain, any progeny with a half life of not more than 10 days, would, for the greater part of the journey, be in secular equilibrium with the longer lived parent nuclide. In such cases the Q values for parent and progeny are calculated and summed to obtain the A_1 or A_2 value (see paragraph I.54 of reference [5]. This provides a means of accounting for progeny with branching fractions less than one.

This explains what is meant by the first half of paragraph 403 of the Regulations which states that;

"In the calculations of A_1 and A_2 for a radionuclide not in Table I, 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; and the activity to be taken into account and the relevant limit to be applied shall be those corresponding to the parent nuclide of that chain."

In other words we ignore all progeny having a half life either less than 10 days, or not greater than that of the parent (provided that the NORM may be considered as "undisturbed and in its natural state"), and simply use in our considerations, the relevant limit, for the parent only since in deriving this limit value, the contributions from such daughters has been included.

Continuing with this discussion, as reflected in paragraph I.55 of reference [5];

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

In such cases the applicable limits are derived by applying the relevant limits for the parent and progeny in the various mixtures calculations (see section 8).

The question then arises, with regard to the application of paragraph 403, if we cannot consider the "radionuclides are present in their naturally occurring proportions" do we treat them as a single radionuclide, or do we treat them as mixtures ? If we are to treat them as mixtures then do we consider all uranium associated NORM to be "natural uranium", as defined above, and treat as a mixture ?

7.0 LOW SPECIFIC ACTIVITY MATERIALS

Low specific activity material: Paragraph 226 staes;

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.

LSA material shall be in one of three groups, (of which only LSA I will be discussed here):

(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;
- (ii) Solid unirradiated natural uranium or depleted uranium or natural thorium or their solid or liquid compounds or mixtures;
- (iii) Radioactive material for which the A_2 value is unlimited, excluding fissile material in quantities not excepted under para. 672; or
- (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.

Of particular interest is Paragraph 226(a)(iv), Analysis of the definition of LSA-1 as applicable to NORM.

The definition of LSA-1 material, Paragraph 226 is thus modified as follows:

- to include only that NORM containing naturally occurring radionuclides which are intended to be processed for the use of these radionuclides

  Note: Hence this category would include NORM used to extract uranium.

- to exclude fissile material in quantities not excepted under paragraph 672, and
  Note: Not relevant to NORM.

- to add radioactive material in which the activity is distributed throughout in concentrations up to 30 times the exemption level.

This definition captures other NORM as LSA-1 but places an upper boundary on their activity as LSA-;

Materials containing radionuclides above the exemption levels have to be regulated. Material with an activity concentration between 10 and 30 times the exemption value is now classified as LSA-1 material. The factor of 30 has been selected to take account of the rounding procedure used in the derivation of the BSS exemption values and to give a reasonable assurance that the transport of such materials does not give rise to unacceptable doses.

8.0 CALCULATION OF EXEMPTION VALUES FOR NORM

The NORM processed by mining and milling operations in South Africa contain only naturally occurring radionuclides, principally from the U-238 decay chain, with minor contributions from the U-235 decay chain and from the Th-232 decay chain.

Page 36 of the Regulations contain a number of footnotes relevant to certain of the radionuclides listed in Table I. In the case of the (b) Footnotes, certain radionuclides have been included with their parent in the calculations of the A_1, A_2 or other Limiting values within Table 1, as they have been considered to be in secular equilibrium with the parent, provided that we can consider the "radionuclides are present in their naturally occurring proportions". Otherwise we treat them as distinct radionuclides and input their measured, or assumed, concentrations into the mixture equations.

Hence, if we assume the radionuclides are disturbed from their natural proportions, and exclude radionuclides having half-lives less than 10 days, then the following radionuclides need be included in the calculation of exemption;

Uranium-238	Th-234	U-234	Th-230	Ra-226	Pb-210	Po-210
Uranium-235	Pa-231	Ac-227	Th-227	Ra-223		
Thorium-232	Ra-228	Th-228				

8.1 The Detailed Calculation

The most EXACT calculation requires DETAILED information on the nuclide concentrations of ALL nuclides present within the NORM. With such EXACT information the calculation can be done.

calculation methodology:

We compute the equation;

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

Where;

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

X(i) is;

- the activity concentration for exempt material
- or the activity limit for an exempt consignment as appropriate for the radionuclide i and
- or the “default” value permitted by the regulator
- or the “conservative” value, if permitted by the regulator

X_m is;

- the activity concentration for exempt material
- or the activity limit for an exempt consignment in the case of a mixture.”

Bearing in mind the factor of x 10 where applicable.

This can be an arduous task, which may be simplified by the use of calculational spreadsheets or “Exemption Calculators”.

8.2 The Ratio Method

This is a fairly simple method but again, would seem to require EXACT information on ALL the radionuclide concentrations within the particular NORM. Once you know your nuclide concentrations you simply assess the equation;

$$\sum_j \left(\frac{C_i}{X_i} \right) \leq 1$$

Bearing in mind the factor of x 10 where applicable.

8.3 The Practicality of Using the Mixture Equations

If the “proper” use of the mixture equations requires EXACT information on ALL the nuclide concentrations within the NORM, then the calculation becomes impractical. Since the user must define the ratio f(i) for each nuclide in the calculation, or input the concentration C(i) in the ratio method, it is difficult to understand how this can be done without measuring all nuclide concentrations, unless we make assumptions on nuclide concentrations where we have not actually measured them. The authors experience suggests that the outcome of the calculation is very sensitive to any assumptions made. Hence the regulator must provide guidance on appropriate assumptions.

The impracticality of the mixture equations, if we require exact data, is the relatively large cost of doing full nuclide analysis on every shipment of NORM. The consignor may well decide that the cost of such detailed analysis of the product outweighs the commercial gain to be had should a detailed analysis classify the product as “not radioactive” from a transport perspective.

Hence the regulator must make an informed decision on the MINIMUM nuclides to be measured in order to demonstrate exemption or non exemption from the Regulations. Guidance must also be given to the industry on which nuclides these are and also on which “default” or “conservative” values the regulator would allow as substitutes for radionuclides not measured.

8.4 Default Values as Permitted by the Regulations

TABLE II: BASIC RADIONUCLIDE VALUES FOR UNKNOWN RADIONUCLIDES OR MIXTURES				
Radioactive Contents	**A_1**	**A_2**	**Activity Concentration for Exempt Material**	**Activity Limit for an Exempt Consignment**
	(TBq)	**(TBq)**	**(Bq/g)**	**(Bq)**
Only beta or gamma emitting nuclides are known to be present	0.1	0.02	1×10^{1}	1×10^{4}
Only alpha emitting nuclides are known to be present	0.2	9×10^{-5}	1×10^{1}	1×10^{3}
No relevant data are available	0.001	9×10^{-5}	1×10^{-1}	1×10^{3}

Since all NORM materials would contain both alpha and beta emitters, in general, we are most likely to use the limits given in the last row of the above Table.

9.0 DISCUSSION

There are a number of very important issues, which warrant discussion. In no particular order these issues are;

9.1 Consignment Limits

For any NORM to be shipped there are two exemption levels. The first one is a concentration in Bq/g, the second one - a total activity of a given consignment. Firstly, MUST the consignment be less than BOTH these exemption limits or is being less than at least one exemption limit enough to label the NORM "non-radioactive" in transport terms ?

Secondly, when doing the calculations, these consignment limits are of the order of < 5 kg and in some cases of the order of grammes. This after allowing, in the calculation, for the extra factor of 10 for NORM not to be used for its radioactive properties.

On the understanding that the exemption values in the Regulations are the same as those in Schedule 1 of the BSS, and on the understanding that the derivation of the BSS values were on the basis that the use of 1 tonne per annum of material, below the exemption value, would result in a "trivial" dose. Furthermore believing that transport scenarios are very much more limited than the wide range of scenarios considered for exemption in general, and thereby they should be less "risky", it becomes difficult to comprehend such minute consignment limits.

9.2 Natural Uranium or U-nat

On the understanding that the various footnotes related to paragraphs 401 – 406 are there to simplify the number of nuclides to consider in an exemption calculation, it becomes important to be able to say when use may be made of these footnotes and when one must ignore them and insert all nuclides in the chain into the calculation. In some cases consignors are happy to say that the NORM is U-nat, irrespective of how it is processed or treated, and hence, for NORM, not to be used for its radioactive properties, anything under 100 Bq/g activity is exempt from the Regulations. If this were true then why would we need the use of radiochemical laboratories?

9.3 The Boundary between LSA –I and LSA-II

The 1985 Regulations contained, what the author considers, purely descriptive definitions of LSA-I or LSA-II. If the authors interpretation is correct, the 1996 Regulations at least introduce a definition of LSA-II which may be related to a “number” associated with the activity concentration. Namely “30” multiplied by the exemption value given in paragraphs 401 – 406. This is a step in the right direction, but again there does not appear to be any radiological justification for the “30”. Could we not relate the LSA-I/LSA-II boundary directly to a potential dose ?

9.4 Use of Default Values

Table II gives default values for the various exemption limits, for single nuclides, for cases where we do not know exactly what the nuclides are. However, when using these default values in mixture calculations, we also need to enter the quantity of each nuclide in the mixture in order to calculate f(i). If we haven’t measured these quantities then how do we enter their concentrations within the NORM exemption calculations? We may suspect that Thorium-234 is present within the NORM, but in what concentration? If we measure the concentration to answer this question then we don’t need to use the default values for single nuclide exemption limits. We may use the values for Thorium-234. We could try making assumptions on the concentrations of the non-measured radionuclides within the mixture, but the authors experience is that the exemption/non-exemption decision is very sensitive to what assumptions we make. Is the author missing the point or are the default values redundant for the mixture calculations?

10.0 CONCLUSION

The issues raised by this paper are what the author wishes to bring to the table for discussion. On the one hand it is hoped that someone more enlightened may resolve these issues. If not then the author would hope that these issues prompt enough discussion to enable a way forward in terms of developing a guide document explaining the exact application of the 1996 Regulations to NORM.

11.0 REFERENCES

[1] IAEA Safety Standards Series
Regulations for the Safe Transport of Radioactive Material
1996 Edition (Revised)
Requirements
No. TS-R-1 (ST-1 Revised)

[2] IAEA Safety Standards
Safety Series No. 6
Regulations for the Safe Transport of Radioactive Material
1985 Edition (As Amended 1990)

[3] IAEA Safety Standards Series
Advisory Material for the IAEA Regulations for the Safe Transport of
Radioactive Material 1996 Edition (Revised)
Safety Guide
No. TS-G-1.1
Vienna (2002)

[4] IAEA Safety Standards
Safety Series No. 115
International Basic Safety Standards for Protection
against Ionising Radiation and for the Safety of Radiation Sources
(1996 Edition)

[5] Application of Exemption Principles to the Recycle and reuse of Materials from Nuclear Facilities.

Safety Series No. 111-P-1.1

International Atomic Energy Agency
Vienna, 1992