Transport of Low-Level NORM – A Case for Consistency and Practicality

Richard R. Rawl and Richard W. Leggett
Oak Ridge National Laboratory, Oak Ridge, TN, USA

John R. Cook, NRC Project Manager
U.S. Nuclear Regulatory Commission, Rockville, MD, USA

ABSTRACT

In 1996 the IAEA adopted a system for exemption of low-level radioactive material from transport regulations based on the principle that exemption values should be commensurate with the risk posed by the material as represented by the maximum potential radiation dose to individuals. For many naturally occurring radionuclides the derived dose-based, radionuclide-specific exemption concentrations were substantially lower than the previous radionuclide-independent definition of radioactive material (70 Bq g^{-1}) due to the stringent dose criterion applied. It was recognized that this would bring large quantities of previously unregulated naturally occurring radioactive material (NORM) handled in industry into the scope of the transport regulations. To minimize the economic impact of the dose-based values, a special provision was included to provide for a 10-fold increase in exemption values for radionuclides in natural material provided the material is not intended to be, and has not previously been, processed for recovery of its radionuclides (the wording regarding previous use was added in 2003). This "10 times" or "10x" provision for certain natural material reflects a second concept underlying IAEA guidance, namely, that a dose criterion may be relaxed within cautious bounds to achieve a balance between practical issues and radiological concerns. On the other hand, restriction of the provision on the basis of past or intended use of the material is inconsistent with the basic principle underlying the Transport Regulations in that there is no risk basis for assigning different exemption values to identical materials on the basis of their past or anticipated use. In fact, under this provision the same material can move in and out of the scope of regulatory control as its anticipated use changes. As a practical matter, safety guidelines for potentially hazardous material should be based on measurable properties of the material and not on intended use. To improve the practicality as well as the consistency of the Transport Regulations as applied to NORM, the 10x provision should be revised to apply to all natural materials, regardless of their intended use.

1.0. INTRODUCTION

In 1996 the International Atomic Energy Agency (IAEA) adopted a system for exemption of low-level radioactive material from transport regulations based on the principle that exemption values should be commensurate with the radiogenic risk posed by the material as estimated in terms of radiation dose [1]. Because equal activities of two different radionuclides in a transported material may represent much different potential dose to humans, this principle results in radionuclide-specific transport exemption values.

The Transport Regulations, referred to as TS-R-1, provides radionuclide-specific exemption concentrations for each of nearly 400 radionuclides. These values are based on a collection of scenarios addressing exposures to workers at a fixed installation or members of the public at a landfill site containing discarded radioactive sources, together with Reference Doses representing a low level of radiogenic risk to the most exposed persons [2]. The primary dose constraint is that the effective dose should not exceed 10 μSv per year to the most exposed individual, which is equivalent to a few tenths of 1% of natural background radiation. Additional but generally less restrictive constraints are specified for skin dose and collective dose commitment to the population [2].

For many radionuclides the exemption concentrations implied by this dose-based system are substantially lower than the previous radionuclide-independent definition of radioactive material (70 Bq g^{-1}) [3]. It was recognized that the more restrictive exemption values could have important economic implications because they would bring huge quantities of natural materials handled in industry, particularly mining and oil production, into the scope of transport regulations. To minimize the economic impact of the dose-based values, a special provision as worded in the current version of TS-R-1 [4] provides for a 10-fold increase in exemption values for radionuclides in natural material (the "10x" provision) if the material is not intended to be, and has not previously been, processed for recovery of its radionuclides (Paragraph 107(e)). The restriction regarding the intended use of the natural material was part of the original version of Paragraph 107(e) [1], but the restriction regarding its previous use was not introduced until 2003 [5].

This paper examines the evolution of current transport exemption values and special provisions for NORM (Section 2), the rationale and dosimetric implications of the 10x provision for NORM (Section 3), and issues arising from the past and intended use (hereafter shortened to PIU) provision of Paragraph 107(e) (Section 4), and proposes modifications of exemption rules for NORM to achieve greater consistency and practicality in the regulations (Section 5). It is concluded that the 10x provision is indeed needed to minimize the economic impact of the radionuclide-specific exemption values on industries and that its use is consistent with the concept that IAEA guidance should provide a balance between practical issues and radiological concerns. On the other hand, the restriction of the 10x provision on the basis of previous or anticipated use of a material introduces inconsistencies and practical problems into the Transport Regulations and should be removed. Inconsistencies in exemption values for NORM arising from their method of derivation are also identified.

2.0. EVOLUTION OF CURRENT TRANSPORT EXEMPTION VALUES AND SPECIAL PROVISIONS FOR NORM

The IAEA report "Regulations for the Safe Transport of Radioactive Material" [3], published in 1985, defined radioactive material as any material having a specific activity greater than 70 Bq g^{-1}. This provided a convenient guideline for exemption of radioactive material from regulatory control but was not justifiable from the standpoint of radiation protection, because dose per unit activity from a radioactive source depends strongly on the particular radionuclides present.

In the early 1990s the Commission of the European Communities (CEC) developed a dose-based system for exemption of radioactive material from regulatory control on the basis of the level of activity of specific radionuclide(s) present. The system is described in a CEC report referred to as RP-65 [2]. The guiding principle of the system is that exemption values should be based on the maximum potential radiation dose received by an individual from exposure to the material. Exemption values are based on the following dose criteria: the effective dose should not exceed 10 μSv per year and the dose to the skin should not exceed 50 mSv per year for the most exposed individual, and the collective dose commitment should be below 1 man-Sv per year of the practice. Dose calculations underlying the exemption values are based on 24 scenarios addressing exposures to workers at a fixed installation or to members of the public at a landfill site containing discarded radioactive sources. For about 77% of the (~300) radionuclides considered, the critical (limiting) exposure scenario is external exposure to a worker from a nearby source. Chronic inhalation of activity in the workplace is the critical scenario for about 18% of the radionuclides, and accidental ingestion of a small source by a member of the public is the critical scenario for about 5% of the radionuclides. None of the scenarios address transport of radioactive material.

Exemption values derived in RP-65 for three naturally occurring chains of radionuclides, the ^{226}Ra, ^{232}Th, and ^{238}U chains, are given in Table 1. In each case the parent radionuclide is assumed to be in secular equilibrium with its radioactive progeny. Both the derived value and the rounded value are listed, along with the limiting exposure scenario.

Table 1. Dose-based exemption values given in RP-65 [2] for three naturally occurring chains

Nuclide[a]	Exemption value (Bq g^{-1})		Limiting scenario in RP-65		
	Calculated	Rounded[b]	Group	Exposure mode	Exposure time
Ra-226+	4.7	10	Public	Ingestion	Acute
U-238N	1.8	1	Worker	Inhalation	2000 h y^{-1}
Th-232N	0.85	1	Worker	Inhalation	2000 h y^{-1}

[a]Plus sign or "N" (natural) after radionuclide name indicates secular equilibrium with all radioactive progeny
[b]Values later adopted for use in the IAEA Basis Safety Standards [6] and TS-R-1 [1]

The principles and exemption values developed by the CEC were adopted by the IAEA in its Basic Safety Standards (BSS, IAEA Safety Series No. 115) [6]. As part of the periodic revision of the transport regulations for radioactive material (TS-R-1) [1], researchers examined whether the exemption values in the BSS were suitable for transport of radioactive material [7]. Using specific transport scenarios, they applied the general methods of RP-65 to develop comparative values for 20 radionuclides representing a range of nuclear decay properties. As illustrated in Table 2 for naturally occurring radionuclides, the transport-specific exemption values were generally lower than the BSS values before rounding to a power of 10 and in some cases were still lower after rounding. It was concluded that the differences were not large enough to warrant a second set of exemption values, and the BSS values were adopted for application to transport.

Table 2. Comparison of exemption values for naturally occurring chains derived in RP-65 [2] and used in the BSS [6] with alternate values based on transport scenarios [7]

Radionuclide	Exemption value (Bq g^{-1})			
	RP-65 and BSS		Based on transport scenarios	
	Calculated	Rounded[a]	Calculated	Rounded
Ra-226+	4.7	10	0.50	1
U-238N	1.8	1	0.49	1
Th-232N	0.85	1	0.31	1

[a]Values used in the BSS [6]

For many naturally occurring radionuclides the BSS exemption values are considerably more restrictive than the threshold specific activity of 70 Bq g^{-1} formerly applied [3]. For example, the exemption value for U-238 in secular equilibrium with its radioactive progeny corresponds to an activity concentration of about 14 Bq g^{-1} for the full chain, the exemption value for Th-232 corresponds to about 10 Bq g^{-1} for its full chain. It was recognized that these more restrictive values could have important economic implications because they would bring huge quantities of materials handled in mining and petroleum industries, and previously defined as non-radioactive, into the scope of transport regulations. As a result, the IAEA provided a further exemption for *"natural material and ores containing naturally occurring radionuclides which are not intended to be processed for use of these radionuclides provided the activity concentration of the material does not exceed 10 times the [tabulated values]"* (Paragraph 107(e), TS-R-1, Revised 1996) [1]. The restrictions on the provision were later extended to material previously processed for use of its radionuclides [5]. The current (2005) version of Paragraph 107(e) of TS-R-1 [4] states that the regulations do not apply to *"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 [tabulated values]"*.

The usefulness of the 10x provision to industry is illustrated by the case of zircon sand, a naturally occurring material used in large quantities due to its refractory properties and chemical inertness. All zircons contain ^{238}U and ^{232}Th and their radioactive progeny in concentrations substantially higher than background levels in soil, with the activity concentration of combined radionuclides in typical commercial zircon approaching 70 Bq g^{-1} (Table 3). The dose-based exemption concentration for ^{238}U plus ^{232}Th, applied to the parent radionuclides but assuming secular equilibrium between the parents and all of their radioactive progeny, is 1 Bq g^{-1}. This is about a factor of 4 lower than the typical activity of ^{238}U plus ^{232}Th in commercial zircon (Table 3). Because zircon sands are not processed for their radionuclides, the 10x provision of Paragraph 107(e) applies, and this material is exempt from regulations.

Table 3. Typical levels of uranium and thorium in commercial zircon [8].

	Typical activity (Bq g^{-1})	
	Parent	Full Chain
U-238	3.1 – 4.4	43 – 61
Th-232	0.4 – 0.8	4 – 8
Total	3.5-5.2	45-70

3.0. RATIONALE AND DOSIMETRIC IMPLICATIONS OF THE 10x PROVISION FOR NORM

3.1. Rationale

The IAEA's system for exemption of low-level radioactive material from regulations takes account of the potential cost of regulatory control as well as the risk presented by unregulated material. For example, target doses are relaxed in some situations on the basis that attainment of the Reference Dose used in the BSS (10 µSv y^{-1}) would be costly or unachievable. Some materials, practices, or exposures are omitted entirely from regulatory control on the grounds that they are not amenable to control (the "exclusion" principle).

Although generally not explicitly identified as a Reference Dose, the value 1 mSv y^{-1} has come to be used in IAEA documents as a kind of dose constraint for low probability events or other situations in which it is not practical to limit dose to a few tens of μSv y^{-1}. For example, in the derivation of exemption values eventually used in the BSS, 1 mSv y^{-1} was used in effect as a Reference Dose for accidents or worst-case situations defined as having a probability of no more than 1% [2]. The rationale was that the probability of a worst-case event times 1 mSv y^{-1} is no greater than the primary Reference Dose of 10 μSv y^{-1}.

The IAEA's principle of relaxing Reference Doses for practical reasons is further illustrated by the approach to derivation of activity concentration values for bulk material in IAEA Safety Standards Series No. RS-G -1.7 (2004) [9] and its background document, IAEA Safety Reports Series No. 44 (SRS No. 44) [10]. The purpose of these documents was to expand on the concepts of exemption, exclusion, and clearance defined in the BSS as they apply to large quantities of low-level radioactive material. (Clearance is defined as removal from any further regulatory control on the basis that the material presents an acceptably low risk regardless of subsequent use.) In these documents, 1 mSv y^{-1} was used as a dose constraint for low probability exposure scenarios for artificial radionuclides. Activity concentration values applicable to naturally occurring radionuclides were not based on exposure scenarios but derived using a pragmatic approach involving a balance between radiation protection and practical considerations. The assigned radionuclide concentration values for naturally occurring radionuclides are consistent with an effective dose no greater than 1 mSv y^{-1} to the maximally exposed person.

RS-G-1.7 emphasizes that regulatory authorities should take account of a graded approach based on the optimization principle for exclusion, exemption, and clearance. That is, if the activity concentration of the radionuclide exceeds the tabulated value in RS-G-1.7, the regulatory body should decide on the extent to which the regulatory requirements set out in the BSS should be applied. The goal is to optimize radiation protection, taking the cost of regulatory control into account. According to Paragraph 5.12 of RS-G-1.7:

> "For activity concentrations that exceed the relevant values [in RS-G-1.7] by several times (e.g., up to 10 times), the regulatory body may decide … that the optimum regulatory option is not to apply regulatory requirements… In many cases, a decision will be made by the regulatory body on a case by case basis … and will take the form of exemption. In some cases, the regulatory body may specify that exposure arising from certain human activities involving activity concentrations of this magnitude need not be regulated." [9]

Thus, the 10x provision for NORM in TS-R-1, Paragraph 107(e), is part of a general IAEA practice of adjusting limiting doses or radionuclide concentration values to achieve a balance between practical issues and radiological concerns. In the following paragraphs we examine whether this provision is also consistent with the "low probability dose constraint" of 1 mSv y^{-1} that has been used in IAEA documents.

3.2. Maximum dose from transport of NORM if the 10x rule is applicable

Because the exemption values of TS-R-1 were based on a limiting dose of 10 μSv y^{-1}, it may at first appear that the application of the 10x provision of TS-R-1, Paragraph 107(e), would increase the maximum potential dose from transport of qualifying material to 100 μSv y^{-1}. It must be taken into account, however, that the tabulated exemption values in TS-R-1 are liberally rounded and that the underlying scenarios [2] do not address transport and generally involve small sources. More realistic scenarios and consideration of derived values rather than rounded values are required to assess the maximum potential dose from unregulated material.

The analysis by Carey et al. (1995) [7] summarized above appears to provide the most realistic dose estimates available for transported low-level radioactive material because it is based on realistic transport scenarios, its dosimetry is supported by field data insofar as comparisons are feasible, and it addresses transport of bulk material as well as small to moderate loads. For most of the radionuclides considered by Carey and coworkers, including all of the natural radionuclides addressed, the limiting transport scenarios involve transport of bulk quantities of material by truck. The analysis indicates that the most highly exposed person typically would be the truck driver, assuming annual driving time of a few hundred hours (although comparable doses were projected to be received by a truck cleaner in the case of Th-232N). The dose to the driver would arise almost entirely from external irradiation due to photon emissions during transport of the material.

Maximal dose estimates from transport of natural material containing Ra-226+, U-238N, or Th-232N were derived using the methods and results of Carey et al. [7]. Results are summarized in Table 4. The maximal estimated dose from unregulated transport of material containing either U-238N or Th-232N is well below the value 1 mSv y^{-1}

applied in IAEA documents as a kind of low probability dose constraint. For Ra-226+ the maximal estimated dose is 2 mSv y^{-1}. The results shown in Table 2 indicate that, in reality, Ra-226+ and U-238N may yield about the same maximal dose from transport and hence, according to the risk principle underlying the exemption values in TS-R-1, ideally would be assigned the same exemption value. The 10-fold difference in exemption values for Ra-226+ and U-238N in RP-65 [2], the BSS [6], and TS-R-1 [1, 4, 5] results in part from limitations in the scenarios of RP-65 and in part from the rounding rules applied.

Table 4. Maximal estimated doses from transport of NORM based on methods of Carey et al. [7]

Radionuclide	TS-R-1 exemption concentration (Bq/g)	Maximum dose (mSv y^{-1})	
		If 10x rule does not apply	If 10x rule applies
Ra-226+	10	0.2	2.0
U-238N	1	0.02	0.2
Th-232N	1	0.03	0.3

4.0. ISSUES WITH THE "PREVIOUS OR INTENDED USE (PIU)" RESTRICTION

4.1. Inconsistency between the PIU restriction and IAEA exemption principles

In contrast to the 10x provision discussed above, the PIU restriction of Paragraph 107(e) of TS-R-1 [4] appears to be at odds with the principles and goals of IAEA guidance on exemption of low-level radioactive material from regulatory control. The restriction does not appear to have a practical basis; in fact, as illustrated later, it introduces unnecessary complexity and cost into transport of material without reducing risk from transport. Also, it violates the principle underlying the BSS exemption system in that it is not risk-informed. From a radiation protection perspective, any restriction of the 10x provision of Paragraph 107(e) should be justified on the basis of projected doses during transport. The PIU restriction implies that past or future extraction of radionuclides from a material either results in higher transport doses from same exposure scenarios (normal or accident), or these materials are transported in a manner resulting in higher doses (e.g., package type or exposure distance). Neither situation appears to be occurring. In effect, the PIU restriction represents a bias against material used in the nuclear fuel cycle, and it may reinforce public misconceptions concerning risk associated with nuclear power.

4.2. Magnitude of potential inconsistencies in exemption values resulting from the PIU provision

It is evident that, as a result of the PIU provision, the exemption concentration for a given material can change by a factor of 10, with no change in risk, on the basis of previous or intended use of that material. Due to a potential multiplicative effect of the PIU provision and other limitations of the TS-R-1 exemption system, even larger inconsistencies can arise between exemption levels for two different radioactive materials. This is illustrated using exemption values for Ra-226+ and U-238N. Results summarized in Table 2 indicate that, per unit activity, Ra-226+ and U-238N yield essentially the same potential maximal dose from transport. The reason for this is that U-238N contains Ra-226+ as a sub-chain, and the risk from transport of both materials results primarily from external dose due to photon emissions from the Ra-226+ chain. Thus, ideally, Ra-226+ and U-238N would be assigned the same transport exemption values according to the risk principle underlying TS-R-1. However, there is a 10-fold difference in exemption values for Ra-226+ and U-238N in TS-R-1, due partly to limitations in the scenarios of RP-65 and partly to the rounding rules applied. If the 10x rule is applicable to a material containing Ra-226+ (e.g., pipe scale) but not to another material containing U-238N (e.g., alternate feed material), then the maximum acceptable dose from unregulated material is reduced to 0.02 mSv y^{-1} for U-238N but remains at 2 mSv y^{-1} for Ra-226+ (see Table 4). This means that, according to the present exemption system for NORM, there can be a 100-fold difference in maximum acceptable doses from two materials that present the same maximal risk per unit activity.

4.3. Illustration of the complexity of the PIU provision and its lack of a risk basis

The schematic in Figure 1 illustrates the potential complexity that the PIU provision introduces into transport regulations as well the lack of relation of the provision to radiogenic risk. Four hypothetical situations are used to show how a radioactive material can move into or out of the scope of transport regulations due to this provision, for reasons that are unrelated to risk. In all four cases, it is assumed that a zirconium ore is mined, then transported 100 km along Route 66 to Site A for extraction of a metal (either U-235 or stable Zr), then transported 100 km along Route 77 to Site B for storage or extraction of the other metal not extracted at Site A (stable Zr or U-235), and finally transported 100 km along Route 88 to a waste repository. It is assumed that the mined ore has a U-238N concentration of almost 10 Bq/g, and that processing for U extraction removes much of the U-235, accompanied by some U-234, but no other radionuclides. At the indicated levels of radioactivity, exemption rules in TS-R-1 determine that the material would have to be under regulatory control if it has been processed in the past to extract U-235 or is intended to be processed for this purpose. Otherwise, the material would be exempt from transport regulations because the nominal exemption value for U-238N is 1 Bq g^{-1} and the 10x rule of TS-R-1, Paragraph 107(e), is applicable.

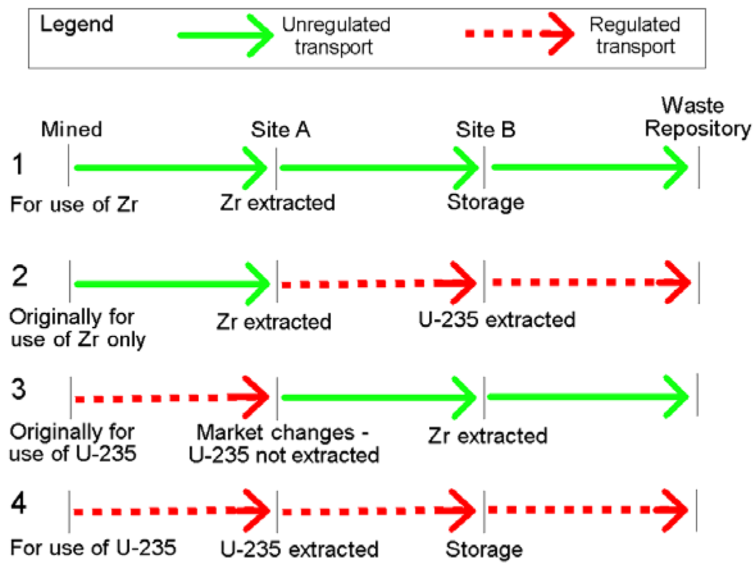

Figure 1. Ilustration of movement of material in or out of the scope of transport regulations on the basis of previous or anticipated uses.

Case 1 (top): The mined ore is intended for extraction of Zr. The ore is transported from the mine to Site A, where Zr is extracted. The processed material is transported to Site B, where it is stored temporarily. The material is eventually transported to a permanent waste storage site. The material never falls within the scope of transport regulations because the U-238N concentration is less than 10 Bq/g (less than 10 times the tabulated exemption value of 1 Bq g^{-1} for U-238N), and the material is never processed for extraction of its radionuclides and never intended for that purpose.

Case 2 (second from top): The mined ore is originally intended for extraction of Zr only. Hence transport to Site A is unregulated. After Zr has been extracted at Site A, the processed material is purchased for use as an alternate feed material and transported to Site B for extraction of U-235. Transport from Site A to Site B is regulated due to the intended use of the material. Uranium is extracted at Site B, and the material is then transported to a waste repository. Transport from Site B to the repository is regulated due to the previous extraction of U-235, even though the radiogenic risk posed by the material is less than in Case 1 (in which transport along the same route was unregulated) because the radionuclide content of the material has now been reduced.

Case 3 (third from top): The mined ore is originally intended for extraction of U-235. Hence, transport from the mine to Site A is regulated. After the ore arrives at Site A, the buyer decides that extraction of U would not be cost effective due to recent changes in market conditions. The material is subsequently sold and transported to Site B for extraction of its Zr. Transport regulations are no longer applicable because the material is no longer intended for extraction of its radionuclides and has never been used for that purpose. After extraction of Zr at Site B, the unregulated material is transported to the waste repository.

Case 4 (bottom): The mined ore is intended for extraction of U-235. Hence transport from the mine to Site A is regulated. The ore is processed at Site A for extraction of U. Thus, due to its previous uses, transport of the material to Site B for temporary storage and transport from Site B to the waste repository site are regulated despite the lowered radiogenic risk posed by the material due to reduction of its radionuclide content at Site A.

To summarize, in the hypothetical cases described above, material moves in and out of the scope of regulatory control on the basis of past or intended uses even though the risk that the material would pose during unregulated transport never increases. Ironically, in some of the depicted situations the factors that bring the material into regulatory control actually reduce the potential dose from transport due to lowering of the radionuclide content.

5.0. SUMMARY AND CONCLUSIONS

The IAEA's system for exemption of slightly radioactive material from transport regulations (TS-R-1) is based on the principle that exemption values should be commensurate with the risk posed by the material, as measured by the estimated maximum annual dose to any individual. This principle results in radionuclide-specific transport exemption values because equal activities of two different radionuclides in a transported material may represent much different potential dose to humans. For many radionuclides the exemption concentrations implied by this dose-based system are substantially lower than the previous radionuclide-independent definition of radioactive material (70 Bq g^{-1}). Because the more restrictive exemption values would have important economic implications by bringing large quantities of NORM into the scope of transport regulations, a special provision is included in TS-R-1 to provide for a 10-fold increase in exemption values for radionuclides in natural material if the material is not intended to be, and has not previously been, processed for recovery of its radionuclides (Paragraph 107(e)) [4].

This paper examines the basis for the current exemption system for NORM and its consistency with the guiding principles of the BSS, with emphasis on the special provisions in Paragraph 107(e). It is concluded that:

- The 10x provision of Paragraph 107(e) is consistent with the IAEA's common practice of relaxing radionuclide exemption concentrations within cautious bounds to achieve a balance between practical issues and radiological concerns.
- Analyses based on realistic transport scenarios indicate that, in cases where the 10x provision is applicable, the maximal annual dose from unregulated transport of natural uranium or thorium would generally be substantially less than the IAEA's "practical dose constraint" of 1 mSv. The maximal dose from unregulated transport of material contaminated with Ra-226 and chain members can be at least two times higher than that practical constraint.
- The previous or intended use provision of Paragraph 107(e) is not justified and should be removed. If exemption values are to be risk-informed, they should be based on dose implications, not on the previous or intended uses of the material being transported. Consequently, allowance of a 10-fold increase in the exemption values for natural material and ores containing naturally occurring radionuclides should be applied to all such material regardless of their past or intended use.
- If Paragraph 107(e) is modified to eliminate the "intended use" clause, it will also be necessary to remove a similar clause from the definition of a category of regulatory materials referred to as LSA-I. This category includes *"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"* [4]. Under the proposed revision, the above wording (*"uranium and thorium ores … for the use of these radionuclides"* would be reduced simply to *"ores containing naturally occurring radionuclides"*.

6.0. REFERENCES

[1] IAEA Safety Standards Series. TS-R-1, 1996 Revised, Regulations for the Safe Transport of Radioactive Material. IAEA, Vienna.

[2] Harvey, M.; Mobbs, S.; Cooper, J.; Chapuis, A. M.; Sugier, A.; Scheider, T.; Lochard, J.; Janssens, A., 1993, Radiation Protection - 65 (RP-65). Principles and Methods for Establishing Concentrations and Quantities

(Exemption Values) below which Reporting Is Not Required in the European Directive. Commission of the European Communities. Report XI-028/93.

[3] IAEA Safety Series No. 6, 1985, Regulations for the Safe Transport of Radioactive Material. IAEA, Vienna (updated 1990).

[4] IAEA Safety Standards Series. TS-R-1, Amended 2005, Regulations for the Safe Transport of Radioactive Material. IAEA, Vienna.

[5] IAEA Safety Standards Series. TS-R-1, Amended 2003, Regulations for the Safe Transport of Radioactive Material. IAEA, Vienna.

[6] IAEA Basic Safety Series 115, 1994, International Basic Safety Standard for Protection against Ionizing Radiation and for the Safety or Radiation Sources. IAEA, Vienna.

[7] Carey, A.; Francois, P.; Harvey, M.; Hughes, J. S.; Lombard, J.; Mobbs, S.; Raffestin, D.; Schneider, T.; Shaw, K. B., 1995, The Application of Exemption Values to the Transport of Radioactive Materials. European Commission. Contract CT/PST6/1540/1123.

[8] Selby, J. H.; Enslin, W.; Slabbert, J.; Strydom, R., 2002, Risk Assessment of the Bulk Transport of Zircon Sands. Completed as Part of an IAEA Coordinated Research Project.

[9] IAEA RS-G-1.7, 2004, IAEA Safety Standards Series No. RS-G-1.7, Application of the concepts of exclusion, exemption and clearance, Safety Guide. IAEA, Vienna.

[10] IAEA SRS No. 44, 2005, IAEA Safety Reports Series No. 44, Derivation of activity concentration values for exclusion, exemption and clearance. IAEA, Vienna.