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Evaluation of Activity Concentration Values and Doses due to the Transport of Low Level Radioactive Material

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Environmental Protection and Waste Services Division

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ABBREVIATIONS AND ACRONYMS

BSS	Basic Safety Standards
CEC	Commission of the European Communities
CRP	Coordinated Research Project
E	effective doses
EDE	effective dose equivalent
EIS	environmental impact statement
HMC	heavy mineral concentrate
IAEA	International Atomic Energy Agency
ISL	in situ leaching
NORM	naturally occurring radioactive material
NPIU	no previous or intended use
PIU	previous or intended use
RnP	sum of radon progeny
RP-65	*Radiation Protection-65*
RS-G-1.7	*Application of the Concepts of Exclusion, Exemption and Clearance Safety Guide, Safety Guide No. RS-G-1.7*
SRS No. 44	IAEA Safety Reports Series No. 44
TIC	Tantalum-Niobium International Study Center
TS-R-1	IAEA Safety Standards, *Regulations for the Safe Transport of Radioactive Material, Safety Requirements No. TS-R-1*

ABSTRACT

The International Atomic Energy Agency (IAEA) initiated an international Coordinated Research Project (CRP) to evaluate the safety of transport of naturally occurring radioactive material (NORM). This report presents the United States' contribution to that IAEA research program.

The focus of this report is on the analysis of the potential doses resulting from the transport of low level radioactive material. Specific areas of research included: (1) an examination of the technical approach used in the derivation of exempt activity concentration values and a comparison of the doses associated with the transport of materials included or not included in the provisions of Paragraph 107(e) of the IAEA Safety Standards, *Regulations for the Safe Transport of Radioactive Material, Safety Requirements No. TS-R-1*; (2) determination of the doses resulting from different treatment of progeny for exempt values versus the A_1/A_2 values; and (3) evaluation of the dose justifications for the provisions applicable to exempt materials and low specific activity materials (LSA-I).

It was found that the "previous or intended use" (PIU) provision in Paragraph 107(e) is not risk informed since doses to the most highly exposed persons (e.g., truck drivers) are comparable regardless of intended use of the transported material. The PIU clause can also have important economic implications for co-mined ores and products that are not intended for the fuel cycle but that have uranium extracted as part of their industrial processing.

In examination of the footnotes in Table 2 of *TS-R-1*, which identifies the progeny included in the exempt or A_1/A_2 values, there is no explanation of how the progeny were selected. It is recommended that the progeny for both the exemption and A_1/A_2 values should be similar regardless of application, and that the same physical information should be used in deriving the limits.

Based on the evaluation of doses due to the transport of low-level NORM, it was concluded that the transport regulations should be revised so that all natural materials (regardless of PIU provided that the ten times limit of Paragraph 107(e) is met) are subject to the same exemption provisions. This approach requires a supporting revision to the material specification applicable to LSA-I materials in *TS-R-1,* Paragraph 409(a)(i). This supporting revision would clarify that all uranium and thorium ores and concentrates, and other ores containing NORM, regardless of their PIU, are included in the LSA-I category if they exceed the ten times provision of Paragraph 107(e).

1. INTRODUCTION

The International Atomic Energy Agency (IAEA) system for exemption of slightly radioactive material from the transport regulations (IAEA Safety Standards, *Regulations for the Safe Transport of Radioactive Material, Safety Requirements No. TS-R-1*[*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. Departures from that principle and inconsistencies between exemption values for naturally occurring radionuclides have resulted from special provisions for natural materials that depend on their previous or intended use (PIU). The current (2009) version of Paragraph 107(e) of *TS-R-1* states that the regulations do not apply to: "natural material and ores containing naturally occurring radionuclides which are either in their natural state, or have only been processed for purposes other than for extraction of the radionuclides, and 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 values specified in Table 2, or calculated in accordance with paras 403–407."

The United States' contribution to the IAEA Coordinated Research Project (CRP) on "The Appropriate Level of Regulatory Control for the Safe Transport of Naturally Occurring Radioactive Material (NORM)" was to examine the technical approaches used in the derivation of exempt activity concentration values and compare doses attributed to the transport of materials that are either included or not included in the provisions of Paragraph 107(e) of *TS-R-1*. The study also evaluated the different treatment of progeny in the determination of A_1/A_2 values, which are derived using the Q-system, and in the determination of exemption values. Finally, the need for supporting revisions to *TS-R-1* were examined to identify the revisions necessary to support implementation of a dose-based approach to low specific activity materials (LSA-I) as well as to exemption values. Section 2 of this report discusses the evolution of current transport exemption values and special provisions for NORM. Section 3 analyzes the rules used to derive the exempt activity concentrations values for various applications in the transport regulations. Section 4 compares doses associated with the transport of ores and ore products that are intended or not intended to be processed for their radionuclides. Section 5 evaluates the dose justifications for exempt materials and LSA-I materials, and Section 6 evaluates the different treatment of progeny in the derivation of A_1/A_2 values and exempt concentration values.

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

The IAEA *Regulations for the Safe Transport of Radioactive Material,* 1985 Edition (updated 1990), Safety Series No. 6 defined radioactive material as any material having a specific activity greater than 70 Bq g^{-1} (IAEA 1990). This provided a convenient guideline for exemption of radioactive material from regulatory control, but it was not justifiable from the standpoint of radiation protection because dose per unit activity of the radioactive material 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" (Harvey et al., 1993). 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 annual effective dose should not exceed 10 μSv (1 mrem), the annual dose to the skin should not exceed 50 mSv for the most exposed individual, and the annual collective dose commitment should be below 1 man-Sv. 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 addresses 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 radioactive progeny are assumed to be in secular equilibrium with the nuclide heading the chain. 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 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
$^{226}Ra^{+}$	4.7	10	Public	Ingestion	Acute
^{238}U nat.	1.8	1	Worker	Inhalation	2000 h
^{232}Th nat.	0.85	1	Worker	Inhalation	2000 h

[a]Plus sign or "nat." (natural) after radionuclide name indicates secular equilibrium with all radioactive progeny.
[b]Values later adopted for use in the IAEA Basic Safety Standards (IAEA 1994) and *TS-R-1* (IAEA 1996)

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* (IAEA 1994). As part of the periodic revision of the transport regulations for radioactive material (*TS-R-1*) (IAEA 1996), researchers examined whether the exemption values in the BSS were suitable for transport of radioactive material (Carey et al. 1995). 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. For some other radionuclides, the transport-specific values 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 (Harvey et al. 1993) and used in the BSS (IAEA 1994) with alternate values based on transport scenarios (Carey et al. 1995)

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

[a]Values used in BSS (IAEA 1994)

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 (IAEA 1990). For example, the exemption value for ^{238}U in secular equilibrium with its radioactive progeny corresponds to an activity concentration of about 14 Bq g^{-1} for the full chain, and the exemption value for ^{232}Th 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 the 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]," (IAEA 1996). Therefore, to minimize the economic impact of the dose-based values, this special provision provided for a 10-fold increase in exemption values for radionuclides in natural material (the "10x" provision) if the material was not intended to be, and has not been, processed for recovery of its radionuclides (Paragraph 107(e) of *TS-R-1*).

The restriction regarding the intended use of the natural material was part of the original version of Paragraph 107(e) (IAEA 1996), but the restriction regarding its previously processed for use of radionuclides was not introduced until 2003 (IAEA 2003). The current (2009) version of Paragraph 107(e) of *TS-R-1* states that the regulations do not apply to: "natural material and ores containing naturally occurring radionuclides which are either in their natural state, or have only been processed for purposes other than for extraction of the radionuclides, and 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 values specified in Table 2, or calculated in accordance with paras 403–407."

3. EVALUATION OF THE DERIVATION OF EXEMPT ACTIVITY CONCENTRATION VALUES

The IAEA's principle of relaxing reference doses for practical reasons is evaluated in this section as it pertains to the derivation of exempt activity concentrations for bulk material. The rationale and dosimetric implications of the 10x provision for NORM in *TS-R-1*, Paragraph 107(e) is examined to determine whether this provision is consistent with the "low probability dose constraint" of 1 mSv that has been used in IAEA documents and whether the "previous or intended use" (PIU) restriction is consistent with the principles and goals of IAEA guidance on exemption of low level radioactive material from regulatory control. The magnitude of potential inconsistencies in the exemption concentration values resulting from the PIU provision is also examined within this section.

3.1 RATIONALE AND DOSIMETRIC IMPLICATIONS OF THE 10x PROVISION FOR NORM

3.1.1 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) 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 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 values in the range of 10 μSv. For example, in the derivation of exemption values eventually used in the BSS, 1 mSv was used in effect as a reference dose for accidents or worst-case situations defined as having a probability of no more than 1% (Harvey et al. 1993). The rationale was that the probability of a worst case event times 1 mSv is no greater than the primary reference dose of 10 μSv.

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, *Safety Guide No. RS-G-1.7* (IAEA 2004) and its background document, IAEA Safety Reports Series No. 44 (SRS No. 44, IAEA 2005b). 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 two documents, 1 mSv 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 were 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 to the maximally exposed person.

Application of the Concepts of Exclusion, Exemption and Clearance Safety Guide (*RS-G-1.7*, IAEA 2004) 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 (IAEA 2004).

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 sections, whether this provision is also consistent with the "low probability dose constraint" of 1 mSv that has been used in IAEA documents is examined.

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 annual dose of 10 μSv, 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. It must be taken into account, however, that the tabulated exemption values in *TS-R-1* are liberally rounded and that the underlying scenarios (Harvey et al. 1993) 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) provides 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 ^{232}Th nat.). 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 $^{226}Ra^{+}$, ^{238}U nat., or ^{232}Th nat. were derived using the methods and results of Carey et al. 1995. Results are summarized in Table 3. The maximal estimated annual dose from unregulated transport of material containing either ^{238}U nat., or ^{232}Th nat. is well below the value 1 mSv applied in IAEA documents as a kind of low probability dose constraint. For $^{226}Ra^{+}$ the maximal estimated dose is 2 mSv. The results shown in Table 2 indicate that, in reality $^{226}Ra^{+}$ and ^{238}U nat. may yield about the same maximal dose from transport, and hence,

Table 3. Maximal estimated doses from transport of NORM based on methods of Carey et al. (1995)

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

according to the risk principle underlying the exemption values in *TS-R-1*, ideally they would be assigned the same exemption value. The 10-fold difference in exemption values for $^{226}Ra^{+}$ and

^{238}U nat. in *RP-65* (Harvey et al. 1993)**,** the BSS (IAEA 1994)**,** and *TS-R-1* (IAEA 1996, 2003, 2005a, 2009) results in part from limitations in the scenarios of *RP-65* and in part from the rounding rules applied.

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

3.3.1 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* (IAEA 2009) 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, or a technically defensible basis; in fact, as illustrated later, it introduces unnecessary complexity and cost into the transport of material without reducing the 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 the 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 other applications using uranium or thorium.

3.3.2 Magnitude of Potential Inconsistencies in Exemption Values Resulting from the PIU Provision

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, due to the basis of the PIU 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 $^{226}Ra^{+}$ and ^{238}U nat. Results summarized in Table 2 (calculations of exemption values based on transport scenarios) indicate that per unit activity, $^{226}Ra^{+}$ and ^{238}U nat. yield essentially the same potential maximal dose from transport. The reason for this is that ^{238}U nat. contains $^{226}Ra^{+}$ as a sub-chain, and the risk from transport of both materials results primarily from external dose due to photon emissions from the $^{226}Ra^{+}$ chain. Thus, ideally, $^{226}Ra^{+}$ and ^{238}U nat. 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 $^{226}Ra^{+}$ and ^{238}U nat. 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 $^{226}Ra^{+}$ (e.g., pipe scale) but not to another material containing ^{238}U nat. (e.g., alternate feed material), then the annual dose from exempted material is 0.02 mSv for ^{238}U nat. but is 2 mSv for $^{226}Ra^{+}$ (see Table 3). This means that according to the present exemption system for NORM, there can be a 100-fold difference in maximum doses from two materials that present the same maximal risk per unit activity.

3.3.3 Illustration of the Complexity of the PIU Provision and Its Lack of a Risk Basis

The schematic of Fig. 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 scenarios are used to show how a radioactive material can move into or out of the scope of the 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 to Site A for extraction of a metal (either U or stable Zr), then transported to Site B for short-term storage or extraction of the other metal not extracted at Site A

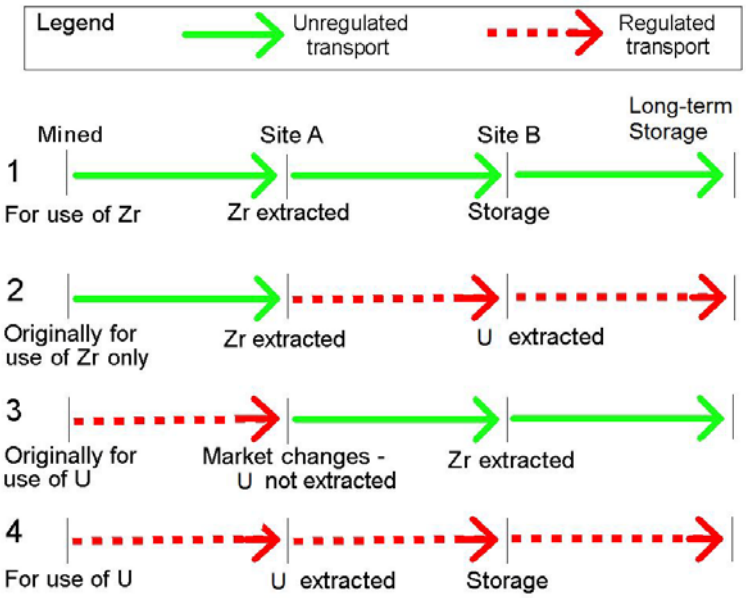

Fig. 1. Illustration of movement of material in or out of the scope of transport regulations on the basis of previous or anticipated uses.

(stable Zr or U), and finally transported to long-term storage. It is assumed that the mined ore has a ^{238}U nat. concentration of almost 10 Bq g^{-1}. The exemption rules in *TS-R-1* specify that the material would have to be under regulatory control if it has been processed in the past or is intended to be processed to extract the uranium and the activity concentration exceeds 1 Bq g^{-1}. Otherwise, the material would be exempt from transport regulations, because the nominal exemption value for ^{238}U nat. is 1 Bq g^{-1} and the 10x rule of *TS-R-1*, Paragraph 107(e), is applicable.

In the case of a mineral ore, which is only processed to extract the mineral, the material is not subject to regulation in transport (scenario 1). There are some mineral ores that are mined/transported as mineral ores, such as tantalum and rare earths, where the residues may be subsequently used as alternate feed for uranium fuel production (scenario 2). In this scenario, the first transport segment is regulated or not based on available knowledge of the "intended use" of the material. Note that in scenario 2, if the material is subsequently processed for removal of the uranium, then the first transport segment was technically in violation of the regulations "after the fact." If the use of the ore changes due to business decisions, such as a drop in uranium prices and a rise in zirconium prices, the ore could move from being regulated to being unregulated (scenario 3). Scenario 4 illustrates how the same material, if it is processed solely for extraction of the uranium, is regulated in transport throughout its lifecycle. These scenarios highlight the illogical basis for regulating the same material based on intended use, and doing so is not technically defensible.

Another scenario exists whereby thorium ore is regulated, but the final/end product is not regulated (e.g., microwave magnetrons, and tungsten inert gas [TIG] welding rods). Though not evaluated in this report, this scenario gives additional reason to question the logic of restricting the 10x exemption only to those products not intended for processing or use of radionuclides.

3.4 SUMMARY OF THE EVALUATION OF 10x PROVISION AND SPECIAL PROVISIONS IN PARAGRAPH 107(e)

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) was examined. Regarding the 10x provision, 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 and close to the "prudent" dose constraint of 0.1 mSv (ICRP 2007).
- The maximal dose from unregulated transport of material contaminated with ^{226}Ra and its chain members can be moderately higher than the "practical dose constraint" and about an order of magnitude higher than the maximum dose from the transport of material contaminated with natural uranium. This difference points out an inconsistency in the current exemption values in that calculations indicate that transport of material containing ^{226}Ra and its chain members should yield approximately the same dose per unit concentration as transport of material containing natural uranium.
- If the 10x provision is acceptable for the transport of material containing ^{226}Ra and its chain members, then it should be acceptable for the transport of material containing natural uranium.

Regarding the PIU provision of Paragraph 107(e), it was concluded that:

- The PIU 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 PIUs 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 related clause from the definition of a category of regulatory materials referred to as "LSA-I."

The PIU restriction of Paragraph 107(e) of *TS-R-1* appears to be at odds with the principles and goals of IAEA guidance on exemption of low level radioactive material from regulatory control.

4. DOSES ASSOCIATED WITH THE TRANSPORT OF ORES AND ORE PRODUCTS

In this section, the PIU provision is further examined to determine whether it has a valid radiation protection basis and whether the PIU restriction represents a bias against material used in producing uranium and thorium (either for their chemical or radiological properties). The materials that would be exempted and not exempted from the Paragraph 107(e) are identified in this section. Production information and material characteristics of these materials are briefly summarized. Measured and estimated doses associated with the transport of ores, which were previously or are intended to be processed for use of the radionuclides, are compared to doses associated with the transport of ores that had no previous or intended use (NPIU) of the radionuclides.

Throughout the remainder of this section, the weight percent of uranium in ore or product will be presented. One weight percent of natural uranium (wt % U) is equal to 250 Bq g^{-1}. Natural uranium includes ^{238}U, ^{235}U, and ^{234}U. Therefore, 10 Bq g^{-1} for natural uranium would be equivalent to 0.04 wt % U. The weight percent of natural thorium may also be given. Natural thorium includes ^{232}Th and ^{228}Th. One weight percent for natural thorium is equal to 40 Bq g^{-1}. This conversion of wt % U to activity concentration does not include decay products (NRC 2001).

4.1 MATERIALS TYPICALLY PROCESSED FOR REMOVAL OF RADIONUCLIDES

As concluded by authors, Rawl, Leggett, and Cook (2007), if exemption values are to be risk informed, they should be based on dose implications, not on the PIUs of the material being transported. Previous studies identified truck drivers transporting ore as those most likely to receive higher doses associated with the transport of ores as described or summarized in Carey et al. 1995, and Xavier et al. 2008.

Materials that are currently excluded from Paragraph 107(e) because of PIU of radionuclides are described in this section. Uranium ores, alternate feed materials, and ores, which may be co-mined or coprocessed with uranium, are described. Copper and vanadium are examples of ores that may be co-mined or coprocessed with uranium.

4.1.1 Production Information and Material Characteristics

4.1.1.1 Uranium ores

According to Denison Mines Corp (Denison 2008**),** the world's nuclear power reactors currently require approximately 180 million lb of U_3O_8 per year. It is anticipated that by 2020 approximately 234 million lb of U_3O_8 per year will be required due to increased nuclear power capacity. Canada and Australia currently account for over 40% of the world's uranium production. The U.S. production represents about 4% of the world production. (See the distribution as shown in Fig. 2.)

Demand for uranium can be supplied through either primary production (newly mined uranium) or secondary sources (inventories, down blending of weapons grade material, and reprocessing of spent fuel rods). There are also other alternate or secondary sources such as ore residues from tantalum production, residues from rare earth material production, and monazite sands. Summarized in the following sections is information on uranium ore production and typical ore grades associated with Canada, Australia, and the U.S.

Canada. Canada accounted for approximately 21% of the world output in 2008 with all production coming mainly from three mine centers in northern Saskatchewan: McArthur River, McClean Lake, and Rabbit Lake. Additional production possibilities include Cigar Lake ore, which would provide feed for the McLean Lake and Rabbit Lake mills, and Midwest ore, which would provide additional feed for the McClean Lake mill (Natural Resources Canada 2008).

McArthur River is considered the world's largest high grade uranium mine. The ore grades at McArthur River average about 21%. The high grade McArthur River ore is blended with special waste (waste rock) from Key Lake to obtain an average grade of approximately 4% (U_3O_8) before it is

treated. The "low grade" ore that these drivers haul is actually the waste material from the mine and can be up to 2% uranium.

McClean Lake started operation in mid-1999 and produced about 2,500 tons/year of U_3O_8 from 2.4% ore up until 2005. Rabbit Lake was brought into production in 1975 but most of the deposit has been mined out, though reserves still exist at Eagle Point where 1,613 tons of U_3O_8 from an ore grade of 2.1% were mined in 2008 (World Nuclear Association, *Uranium Production in Canada* 2009).

At sites other than McArthur River, the low grade ore can be a much lower grade than at McArthur and is hauled as "special waste." In discussions with Cameco Corporation (Canada), the grade of the low grade ore at these other sites can vary from 0.15 to 2%. The average is nearly always between 0.15 and 0.20% according to monthly geology reports. These average percentages equate to approximately 38 Bq g to 50 Bq g (uranium in ore) for these low grade ores. (See Appendix A for additional information on Canadian uranium resources.)

All the mentioned Canadian uranium resources exceed the 10 Bq g^{-1} concentration criterion; therefore, transportation of these ores is not within the applicability of Paragraph 107(e), and these ores would always be subject to regulation during transport.

Australia. There are three operating uranium mines in Australia: Ranger in the Northern Territory, Olympic Dam, and Beverley in South Australia. A fourth is expected to start operation in 2009: Honeymoon in South Australia (World Nuclear Association, *Australia's Uranium Mines* 2009). Olympic Dam mine contains uranium and copper, as well as silver and gold in close association, and consists of the largest known uranium ore body (350 m below the surface) in the world. Table 4 summarizes the U_3O_8 ore grade and tonnages.

Table 4. Olympic Dam uranium ore reserves and resources

	Ore or resource (million tons)	Grade U_3O_8 (%)	Contained U_3O_8 (tons) calculated
Proved ore reserves	188	0.060	112,800
Probable ore reserves	401	0.059	236,590
Measured resources	1,250	0.033	412,500
Indicated resources	4,623	0.028	1,294,440
Inferred resources	3,207	0.023	737,610
Total resources	9,080	0.027	2,452,000

Source: World Nuclear Association 2009

As shown in Table 4, measured, indicated, and inferred uranium resources at Olympic Dam could have uranium concentrations less than 10 Bq g^{-1}. However, these ores are processed at the site and are not transported offsite in their original state.

United States. The United States produces about 4% of the world's uranium production. Uranium mining in the U.S. is conducted by only a few companies on a relatively small scale. Uranium production from the only uranium mill in operation (White Mesa, Utah) and 6 in situ leaching (ISL) operations totaled 1,503 tons uranium (1,774 tons U_3O_8) in 2008. However, uranium exploration is being undertaken by a number of companies and often goes into areas that were mined in the 1950–1980s (World Nuclear Association, *US Uranium Mining and Exploration* 2009). In 2008, U.S. mines produced 3.9 million lb (1,950 tons) of uranium, 15% less than in 2007. Overall, there were 16 mines that operated during part or all of 2008 (EIA 2009).

In the U.S., the Colorado Plateau district is an area that encompasses approximately 20,000 $miles^2$ and straddles the border of southeastern Utah and the southwestern Colorado. The bulk of the mineral deposits in the Colorado Plateau district are contained in three areas: the Sunday Mine complex (Sunday/St. Jude, West Sunday, Topaz, and Carnation mines), the La Sal complex (La Sal, Beaver, and Pandora mines), and the East Canyon Area, which includes the Rim mine. All of these areas have

developed permitted mines that had been shut down in the 1990s. The uranium grades of the uranium ore from the individual mines are shown in Table 5.

Table 5. Uranium and vanadium ore grades and production

	2007			2008		
	Tons	**% U_3O_8**	**% V_2O_5**	**Tons**	**% U_3O_8**	**% V_2O_5**
Pandora	32,444	0.25%	1.34%	52,623	0.23%	1.22%
Sunday/St. Jude	10,879	0.16%	0.86%	27,497	0.19%	1.04%
West Sunday	16,526	0.17%	0.92%	30,121	0.21%	1.13%
Topaz	7,753	0.16%	0.86%	9,707	0.13%	0.70%
Rim	-	-	-	2,238	0.04%	0.40%
Beaver	-	-	-	729	0.26%	1.41%
Range or Total	*67,602*	*0.16%–25%*	*0.86–1.34%*	*122,915*	*0.04–0.26%*	*0.4–1.4 %*

Source: Denison Mines, *U.S. Mining, Colorado Plateau* 2009

Most of the U.S. uranium ores mentioned have activity concentrations well above 10 Bq g^{-1}. However, as shown in Table 5, the uranium ore grade at the Rim mine is 0.04%, which would result in a uranium activity concentration of about 10 Bq g^{-1}.

These mines are located approximately 65 to 100 miles northwest of Denison's White Mesa mill. Haulage of the ore from the mines to the mill is along county and state highways (Denison Mines, *U.S. Mining* 2009).

4.1.1.2 Multielement ores—copper and vanadium

Copper. Copper is usually found in nature in association with sulfur. However, an increasing amount of copper is produced from acid leaching of oxidized ores. In 2008, 15.7 million tons of copper were produced throughout the world. The major copper producing nations were: Chile (5.6 million tons), the U.S. (1.3 million tons), Peru (1.22 million tons), Australia (0.85 million tons), and Russia (0.75 million tons) (USGS, *Copper Statistics and Information* 2009).

Major Australian copper mining and smelting operations are located at Olympic Dam (South Australia), Mt. Isa (Queensland), Western Australia, and Tasmania. Olympic Dam mine contains uranium and copper, as well as silver and gold in close association. The common procedure of selling copper concentrate with precious metals has not been feasible because of the uranium processing and safeguard issues. Numerous steps are required to remove the uranium from the copper concentrates.

At Olympic Dam, no copper ore or concentrates are currently shipped for off-site processing with the exception of samples for laboratory analysis or research purposes. The ore contains approximately 600 ppm U_3O_8 (13 Bq g^{-1}) and the average copper grade is 1.8%. For refined copper product, all radionuclide concentrations are below that required by the London Metal Exchange, where all radionuclides are to be below 0.01 Bq g^{-1}, with the exception of ^{210}Po, which needs to be below 0.3 Bq g^{-1} (Lawrence 2009).

The *Draft Environmental Impact Statement* for the Olympic Dam expansion states that approximately 1.6 Mtpa of copper concentrate produced from the mine expansion would be exported and most likely transported by rail. The copper concentrate is expected to contain about 1000 to 2000 ppm uranium (25 to 50 Bq g^{-1}) (BHP Billiton 2009).

Vanadium. There is no single mineral ore from which vanadium is recovered. It is found as a trace element in a number of different rock materials and is a by-product of other mining operations. Vanadium is found in: magnetite (iron oxide) deposits, which are rich in titanium, bauxite (aluminum ore) rocks with high concentrations of phosphorous-containing minerals, and sandstones that have uranium content. Vanadium is also recovered from carbon-rich deposits such as coal, oil shale, and tar sands (Mineral Information Institute 2009). So depending on the deposit, vanadium can be either NPIU or PIU.

For 2008, world vanadium mine production was 60,000 metric tons, with South Africa, China, and Russia as the largest producers (USGS, *Vanadium*, "Mineral Commodity Summaries," 2009). In the U.S., vanadium resources are usually associated with uranium ores in sandstones, and the resources are large enough to supply U.S. vanadium needs. However, it is often less expensive to import vanadium and ferrovanadium products (Mineral Information Institute 2009).

White Mesa uranium mill is licensed to recover and produce vanadium. Vanadium is present in some of the ores and is solubilized with the uranium during the leaching process. The vanadium recovery process consists of a separate solvent extraction circuit to treat the uranium raffinate and precipitate the vanadium from the strip solution. Ammonium metavanadate and vanadium pentoxide (V_2O_5) (black flake) are final products.

According to Denison Mines, for every pound of U_3O_8 produced, White Mesa's vanadium coproduct recovery circuit produces approximately 4 lb of vanadium in the form of vanadium pentoxide. It was anticipated for 2008 that 1.5 to 2.0 million lb of vanadium would be produced (Denison Mines, *White Mesa Mill* 2009).

4.1.1.3 Alternate feed materials

White Mesa mill is a conventional uranium processing mill with a vanadium coproduct recovery circuit. It is strategically located within hauling distance of the Denison's current U.S. mine and exploration properties. The mill is licensed to process an average of 2,000 tons per day of ore and produce 8.0 million lb of U_3O_8 per year (Denison Mines, *White Mesa Mill* 2009).

White Mesa is also licensed to process alternate feed materials: uranium bearing materials derived from uranium conversion, tantalum, and other metal processing facilities or material for U.S. government cleanup projects (Denison Mines, *White Mesa Mill* 2009). Usually classified as waste by-generators of the material, Denison processes the material, reclaiming the uranium and disposes of the remaining by-product in the mill's licensed tailing cells (Denison Mines, *White Mesa Mill* 2009).

In 2007, White Mesa produced approximately 254,000 lb of U_3O_8 from alternate feed materials. Appendix B lists the alternate feed materials that White Mesa is licensed to process. Average uranium content in the alternate feed materials ranges from 0.009 to 65%. Selected soils have an average wt % U of about 0.01%, which would result in uranium activity concentrations less than 10 Bq g^{-1}. These alternate feed materials would be exempt if not PIU. If it had been known beforehand that these materials would be used as alternate feed materials, technically even the mining and processing of these ores could be subject to regulation since ultimately the uranium was extracted for use. Ore residues from tantalum production, lead sulfide pond residues from rare earth production, and monazite sands are licensed alternate feed materials. For these ore residues, the average wt % U varies from 0.05 to 0.34%, which would equate to a range of about 13 to 85 Bq g^{-1}. These materials would be regulated even if the PIU provisions were removed.

4.1.2 PIU—Transportation Information and Doses

Summarized below is information on transportation operations and doses associated with the transport of PIU ores and products. These include: uranium ore, copper and vanadium (as co-mined materials), and alternate feed materials.

4.1.2.1 Uranium ore—transportation operations and characterization

As mentioned earlier, "low grade" ore in Canada can vary from 0.15 to 2% uranium. The average uranium content is nearly always between 0.15 and 0.20% according to monthly geology reports. These average percentages equate to approximately 38 Bq g^{-1} to 50 Bq g^{-1} (U in ore) (Charette 2009).

The low grade ore that these drivers haul is waste material from the mine. The mine typically ships 3 loads per person per 12 hr shift. Each load is about 38,000 kg of material per truck. The driver spends 0.5 hr during loading, 1.25 hr driving to the mill, 0.25 hr unloading, 0.5 hr loading clean sand, 1.25 hr driving back to the mine, and 0.25 hr unloading the sand. Then, this process is repeated. The

truck drivers may haul low grade uranium ore, contaminated garbage, and clean material (nonmineralized materials). However, they do not haul other minerals (Charette 2009).

The low grade ore (waste rock) is transported in a truck with the following dimensions: from the front of the trailer to the "headache rack" is about 10 to 12 ft. The rack is about ¼ in. steel. The rack to the back of the cab is about 1 ft. The front 6 to 8 ft of the trailer is never loaded with "low grade" ore because to it too heavy to hoist. The trailer (tub) is about 2 in. of steel on the sides and about 3 in. on the bottom. The box has about a 25 m^3 capacity. Each load is about 38,000 kg of material per truck (Charette 2009).

4.1.2.2 Measured doses associated with the transport of uranium ore

As shown in Table 6, the 2007 and 2008 annual average effective doses (E) for a low grade ore driver was 0.02 and 0.07 mSv, respectively. The 2007 and 2008 maximum annual Es for the low grade ore drivers were 0.43 and 0.54 mSv, respectively. The gamma dose was measured using Optically Stimulated Luminescence Dosimetry. The sum of the long lived radioactive dust is estimated using time and personal dust sampling results. The sum of radon progeny (RnP) doses was estimated using time and area RnP results.

Table 6. Low grade uranium ore transport and measured annual doses

Worker	Ore grade (%)	Uranium concentration (Bq/g)	2007 Annual total effective dose (mSv)	2008, Annual total effective dose (mSv)
Transport drivers	0.15–0.2%	38–50	Average: 0.02 Maximum: 0.43	Average: 0.07 Maximum: 0.54

Source: Charette 2008, 2009

In addition to Cameco, other companies were contacted with requests for information on truck driver doses associated with the transport of uranium ore. These doses and corresponding ore grades are summarized below in Table 7.

Table 7. Doses associated with the transport of uranium ore and concentrates

Industry source	Worker	Ore grade	Material type	Annual Dose (mSv)	No. of workers
Cameco (Charette 2008)	Transport ore truck	0.15–0.2%	Low grade ore (waste rock)	2007 (mean): 0.02 2008 (mean): 0.07	29
Cotter (Cain 2009)	Transport ore truck	0.25%	Uranium ore	0.05	1
Canadian Study (CNSC 2002)	Transport	NA	Uranium ore	Mean: 0.18, range: 0–0.36	4
Cameco (Charette 2008)	Transport ore truck	18%	High grade ore	Mean: 0.8, range: 0.05–3.8	Range 6–15

NA—not available

For uranium ore transport drivers, hauling uranium ore with ore grades between 0.15 and 0.25%, the estimated annual doses ranged from about 0.02 to 0.07 mSv. Ores are transported in off-loaders/dump trucks. Unlike the lower grade ores, the high grade ore is transported in a special B-train type trailer in which the hoppers containing the ores are at a greater distance from the driver.

4.1.2.3 Transportation characteristics and doses—copper and vanadium

Copper. At the Olympic Dam mine, copper ore is processed onsite, and they currently retain the tailings. No copper ore or concentrates are currently shipped for off-site processing with the exception

of samples for laboratory or research analysis. Such samples can be up to 2 tons per shipment. Uranium in uranium/copper ore is considered to consist of about 600 ppm U_3O_8 with all uranium progeny in equilibrium, which would result in approximately 13 Bq g^{-1} (U nat.). Dose rates associated with the transport of these copper samples are considered to be at background (Lawrence 2009).

According to the *Olympic Dam Expansion Project, Draft Environmental Impact Statement* (EIS), approximately 1.6 million tons per year of copper concentrate produced from the expanded mine operations will be exported. Copper concentrate is anticipated to contain radionuclides approximately equivalent to ore of about 1,000 to 2,000 ppm (25 to 50 Bq g^{-1}). It is anticipated that the copper concentrate will be transported by train. In the EIS, the doses to the train crew were considered to be similar to the doses to truck drivers that transport uranium oxide; though the distance between the train crew and the load would be greater, the exposure time for the train crew would be considerably longer (BHP Billiton 2009). Measured dose rates made in a truck cabin averaged about 1 µSv h^{-1}. A driver is assumed to make 100 8-hour trips with uranium oxide annually. The annual dose is estimated to be 0.8 mSv. As mentioned the train crew was assumed to have an equivalent dose to the uranium oxide truck drivers.

Vanadium. For every pound of U_3O_8 produced, White Mesa's vanadium co-product recovery circuit produces approximately 4 lb of vanadium in the form of vanadium pentoxide (V_2O_5) (Denison Mines, *White Mesa Mill* 2009). As shown in Table 5, the wt % of U_3O_8 in 2008 associated with vanadium pentoxide ranges from 0.04 to 0.26% with the lower uranium ore grade (0.04%) having an activity concentration of about 10 Bq g^{-1}.

The vanadium pentoxide product must meet release standards for any trace concentrations of radionuclides (White Mesa 2007). According to personnel at White Mesa, the total activity in the vanadium products needs to be below 80 Bq g^{-1} and for domestic shipments, radiological measurements of the material must also be below 80 µR h^{-1} (at contact) (Turk 2009). The measured dose rate at 1 m is about 0.5 µSv h^{-1} (Turk 2009). The majority of vanadium shipments have had total activity concentrations of about 25 Bq g^{-1} (total uranium activity of about 0.3 Bq g^{-1}), with the highest total activity concentrations ranging from 45 to 50 Bq g^{-1} (Turk 2009). The total uranium activity of 0.3 Bq g^{-1} is less than the 1 Bq g^{-1} exemption value; therefore, it would be exempt from regulation. The contribution to the total activity concentration in the vanadium product is due primarily to progeny.

The vanadium product is shipped domestically throughout the U.S. via truck and train, and typically to Pennsylvania. The product is shipped in 55-gal drums and normally 72 drums per shipment, 4 drums per pallet. The trucks are typically 53 ft trailers. It was assumed that the truck driver was exposed for 24 hr per trip (including sleeping period) and made at least 6 trips per year (Turk 2009); the estimated annual dose using the measured dose rate at 1 m of 0.5 µSv h^{-1} would be about 0.07 mSv.

4.1.2.4 Transportation characteristics and doses associated with the transport of alternate feed material

White Mesa produced in 2007 approximately 254,000 lb of U_3O_8 from alternate feed materials. As shown in Appendix B, average uranium content in the alternate feed materials ranges from 0.009 to 65% (2.3 to 1.63E4 Bq g^{-1}). Contaminated soils had average activity concentrations less than 10 Bq g^{-1}. Ore residues from tantalum production and lead sulfide pond residues from rare earth production are licensed alternate feed materials. For these ore residues, the average wt % U varies from 0.15 to 0.34% which would equate to a range of about 38 to 85 Bq g^{-1}. Summarized below are the activity concentrations, weight percent, and doses associated with the transport of these materials. Appendix B lists the alternate feed materials White Mesa is licensed for processing at the mill.

Tantalum ore residues. One of the alternate feed materials used at White Mesa mill is ore residues from tantalum production. Typically, the material is sent to White Mesa in an intermodal freight container with a hard top (25 yd^3); each lined intermodal will contain on average about 40,500 lb (~ 20.3 tons) of residue. The uranium and thorium content of the ore residue will be 1 to 1.5% (0.75% U and 0.25% Th); whereas, the tantalite ore uranium and thorium content (total) is about 0.5% (U ~ 0.4% and Th < 0.1%) (Eves 2009).

Surface intermodal dose rates ranged from 0.007 and 0.014 mSv h^{-1} and at 2 m the maximum dose rate was about 0.002 mSv h^{-1}. The 2 m measurements generally were taken close to the truck cab. Typically, the ore residue is shipped to White Mesa during campaigns. Each campaign may contain between 250 and 700 tons. Since 2004 there have been about 4 campaign shipments. Usually, two truck drivers haul the residue to the rail spur which is located about 7 miles from the facility; this is assumed to take about a half hour. It takes about 2 to 3 weeks for a shipment to reach White Mesa. In Utah, the intermodal freight container is then trucked to White Mesa which is about 1 hr from the train spur (Eves 2009).

Based on the two transport routes, amount of material transported for each campaign, and number of campaign shipments, the estimated annual dose to the transporter taking the residue to the train spur ranged from 0.01 to 0.04 mSv. The annual dose to the transporter hauling the residue from the train to White Mesa mill was estimated to range from 0.02 and 0.07 mSv.

Rare Earth—lead sulfide residues. According to a technical memorandum regarding the removal of lead sulfide pond solids and the transport to White Mesa mill, the truck cabs remain outside the exclusion area during loading. The material was loaded into lined end-dump trucks. The drivers were instructed to not leave the truck during loading. At least 20 drivers were to be involved in the project. The doses to the truck drivers were expected to be significantly lower than the workers excavating or loading the materials. It was expected that no driver would be exposed greater than 36 hr per week (Johnson 2002). The duration of the project was estimated to take 5 to 6 weeks. It assumed that a trip from Molycorp to White Mesa would take 24 hr since the drivers need to hold over after 10 hr (Espinoza 2009). The truck driver exposure duration was estimated to be 36 hr per week (Johnson 2002). With a project duration of 6 weeks and 36 hr per week, the exposure duration is estimated to be 216 hr. The time weight exposure rate at 1 m above the ponds, 67 µR h^{-1}, and a factor of 0.7 rem R^{-1} , the estimated (maximum) annual dose is approximately 0.1 mSv.

Summarized in Table 8 are the uranium and thorium by mass percentages, activity concentrations, measured or estimated dose or exposure rates, and estimated doses associated with the transport of alternate feed materials.

Table 8. Alternate feed material—percent by weight and doses

Alternate feed	U/Th (%)	Uranium/thorium concentration (Bq g^{-1})	Dose rate	Estimated doses/campaign mSv	Source
Tantalum residues	1–1.5% (U + Th) 0.75% U 0.25% Th	 188 U 10 Th	0.002 mSv h^{-1} @ 2 m	Short trip: 0.01–0.04 Longer trip: 0.02–0.07	Eves 2009
Rare earth—lead sulfide pond residues	0.15% U	38 U	67 µR h^{-1} @ 1m	0.1	Johnson 2002

4.1.3 PIU—Normalized Transportation Activity Concentrations Based on an Annual Dose of 10 µSv

The doses associated with the transport of the aforementioned PIU materials varied due to activity concentration and exposure parameters. In particular, the exposure durations varied considerably from the 400 hr used to derive the exemption values. To compare to the exemption values, the actual annual doses were normalized to account for an exposure duration of 400 hr. As shown in Table 9, the resulting normalized annual doses range from 0.04 to 0.9 mSv. Using the ratio of normalized doses to actual activity concentrations in the ores/products, the derived activity concentrations resulted in an annual dose of 10 µSv, ranging between 1 and 14 Bq g^{-1}.

Table 9. PIU—activity concentrations, exposure durations, actual and normalized doses and comparison to exemption values

Material category >10 Bq g^{-1}	Uranium conc. (Bq g^{-1})	Thorium conc. (Bq g^{-1})	Exposure duration (hr/year)	Estimated annual doses (mSv)	Normalized annual doses based on 400 hr exposure duration (mSv)	Derived U +Th activity concentration (Bq g^{-1}) to 10 µSv (corrected for 400 hr exposure duration)
Copper concentrate	25–50		800	0.8	0.4	1
Rare earth lead sulfide residues	38		216	0.1	0.19	2
Low grade uranium ore	38–50		Mean: 224	2007: 0.02 2008: 0.07	2007: 0.04 2008: 0.13	2007: 11–14 2008: 3–4
Uranium ore	63		408	0.52	0.5	1.2
Tantalum ore residue	188	10	Short: 18 Long: 35	Short trip: 0.01–0.04 Long trip: 0.02–0.07	Short: 0.2–0.9 Long: 0.2–0.8	Short: 2–9 Long: 2.5–9

4.2 MATERIALS NOT NORMALLY PROCESSED FOR REMOVAL OF RADIONUCLIDES

Naturally occurring radioactive materials occur in a number of mineral ores and sands. The focus of the following sections is on mineral ores or sands and associated products which can potentially transition in and out of regulation based on PIU. Below is a review of available production and dose information associated with tantalum, rare earths, and zircon/heavy mineral sands.

4.2.1 Production Information

4.2.1.1 Tantalum

Tantalum material can be defined as encompassing the tantalite mineral concentrates [Fe, Mn $(Ta, Nb)_2O_6$] where tantalum content is greater than the niobium content, as well as slag materials which are by-product of smelting operations (e.g., tin smelting) and contain varying levels of tantalum. Naturally occurring radioactivity contained in tantalum raw material (concentrations and slags) is uranium, thorium, and their radioactive decay products (TIC 2007).

In 2008, about 815 tons of tantalum was produced worldwide. Most tantalum resources are located in Australia (435 tons), Brazil (180 tons), and Canada (45 tons) though there are also resources located in Ethiopia (77 tons) and Rwanda (42 tons). There has been no significant U.S. tantalum mine production since 1959 (USGS, *Tantalum*, "Mineral Commodity Summaries," 2009). The tantalum raw materials, which are transported, are mineral concentrates with uranium and thorium in the crystal lattice so these elements are not removed by physical processing at or near the mine site and are present when the materials are shipped.

Table 10 summarizes the ^{238}U and ^{232}Th activity concentrations in the shipments evaluated by the Tantalum-Niobium International Study Center (TIC). Overall, the ^{238}U concentrations are higher than the concentrations of ^{232}Th with mean concentrations of 16.4 and 1.3 Bq g^{-1}, respectively, in tantalite materials. However, the ^{232}Th concentrations tend to be higher in slag materials compared to concentrations in tantalite materials (TIC 2007).

Table 10. Uranium and thorium activity concentrations

Radionuclide	Material type	Number of shipments	Reported as "<" (%)	Median (Bq/g)	Mean (Bq/g)	Min. (Bq/g)	Max. (Bq/g)	Proportion >10 Bq/g (%)
^{232}Th	Slag	22	0	5.9	6.5	1.8	27.8	5
^{232}Th	Tantalite	45	24	0.5	1.3	0.2	11.1	2
^{238}U	Slag	22	0	3.7	18.8	2.4	92.2	23
^{238}U	Tantalite	45	0	13.6	16.4	4.5	68.1	71
Total	Slag	22		9.7	25.3	7.4	96.8	45
Total	Tantalite	45		14.2	17.7	5.3	68.3	78

Source: TIC 2007

The concentrations of other radionuclides in the uranium and thorium decay series were found to be generally comparable to the concentrations of the parent radionuclides (i.e., ^{238}U and ^{232}Th). In most cases, there were no radionuclides with concentrations consistently and substantially higher or lower than the concentrations of the parent radionuclide. Therefore, an assumption of equilibrium within each of the uranium and thorium decay series is reasonable (TIC 2007).

4.2.1.2 Rare earth materials

The rare earths are a moderately abundant group of 17 elements comprising the 15 lanthanides, scandium, and yttrium (USGS, *Rare Earths,* "Minerals Yearbook;" USGS, *Rare Earths,* "Commodity Summaries" 2007). U.S. and world resources are contained primarily in bastnasite and monazite. Bastnasite deposits in China and the U.S. constitute the largest percentage of the world's rare earth economic resources; whereas, monazite deposits in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, and Thailand constitute the second largest segment (USGS, *Rare Earths* "Mineral Commodity Summaries" 2009). In 2008, approximately 124,000 metric tons of rare earth oxides were mined (USGS, *Rare Earths* "Mineral Commodity Summaries" 2009). In addition to those countries mentioned, there are also other rare earth deposits, such as those found in Canada (Quest Uranium 2009) and Greenland (Greenland Minerals and Energy 2009) where rare earths and uranium could also be co-mined.

In 2008, rare earths were not mined in the U.S.; however, rare earth concentrates previously produced at Mountain Pass, California were processed and other rare earth products were available from stocks (USGS, *Rare Earths* "Mineral Commodity Summaries" 2009). Table 11 summarizes recent activity concentrations in the rare earth products. Depending on the purity of the particular rare earth product, the thorium and uranium content can vary from trace amounts up to about 0.25% by weight (primarily as thorium phosphate).

Table 11. Radioactivity in the Mountain Pass rare earth materials

Material	^{232}Th (Bq g^{-1})	^{238}U (Bq g^{-1})	Source
Ore	1	0.3	Johnson 2009
Bastnasite	4.6	0.8	Johnson 2009
Leached bastnasite	5.3	1	Johnson 2009
Cerium	9	0.7	Johnson 2009
Lanthanum	0.04	0.07	Johnson 2009
Lead sulfide residues (ponds)	0.9, 0.8, 3.3 (in each pond)	11, 23.5, 7.7 (in each pond)	Espinoza 2009

In 2002, the lead sulfide residues were sent to White Mesa uranium mill to be used as alternate feed (Johnson 2002). Contracted trucks are used to haul the lead/iron filter cake to White Mesa; according to Johnson (Johnson 2009), they are not used to also transport rare earth minerals.

4.2.1.3 Zircon/heavy mineral sands

All mineral sands are considered to be NORM, due to the presence of thorium and uranium in mineral grains. The three primary products of the mineral sands industry are called "heavy sands" due to their specific gravity (Calytrix 2008):

- Rutile = 4.2, typical titanium content ~ 60%
- Ilmenite = 4.5–5.0, typical titanium content ~ 60%
- Zircon = 4.6–4.7, zirconium silicate

Another important product is synthetic rutile, which is essentially an "upgraded" ilmenite after thermal and chemical treatment to remove iron oxides and therefore, produce a material with a higher percentage of titanium (Calytrix 2008).

The zirconium-silicate mineral zircon is produced as a coproduct or by-product from the mining and processing of heavy minerals. In 2007, the leading producers of zirconium mineral concentrates were Australia and South Africa. Excluding U.S. production, world production of zirconium was about 1.42 million metric tons (USGS, *Zirconium,* "Minerals Yearbook" 2009). In 2008, the production of zircon in the U.S. was withheld due to company proprietary data; however, export of zirconium oxides and concentrates was about 34,100 tons and about 3,310 tons of zirconium oxide was also exported (USGS, *Zirconium* "Mineral Commodity Summaries" 2009).

As a rule, the elements, ^{232}Th and ^{238}U, decay chains are present in the minerals in the state of equilibrium. Typical content of radioactivity in different products are shown in Tables 12 and 13.

Table 12. Typical activity concentrations (industry data)

Material	Th (Bq g^{-1})	U (Bq g^{-1})	Sum (Bq g^{-1})
Part 1: Materials transported between mines and en route mine → plant → mine			
Heavy minerals concentrate (HMC)	0.5–6.0	0.3–2.5	0.8–8.5
Intermediate products and tailings returned to the mine	2.4–7.2	0.9–2.0	3.3–9.2
Part 2: Materials transported from plants to customers overseas			
Zircon	0.8–1.1	3.2–3.8	4.0–4.9
Ilmenite	0.5–1.9	0.1–0.5	0.6–2.4
Rutile	0.2–0.6	0.1–0.8	0.3–1.4
Synthetic rutile	0.4–1.9	0.1–0.5	0.5–2.4

Note: Monazite concentrations are classified as "radioactive" so for purposes of transport were not included.
Source: Calytrix 2008

Table 13. Average activity concentrations in study

Material	Th (Bq g^{-1})	U (Bq g^{-1})	Sum (Bq g^{-1})
Heavy minerals concentrate (HMC)	1.6	0.6	2.2
Intermediate products and tailings returned to the mine	5.1	1.7	6.8
Zircon	0.9	3.0	3.9
Ilmenite and synthetic rutile	1.2	0.2	1.4

Source: Calytrix 2008

In the Calytrix study, there was no discussion of either uranium or thorium coprocessing; therefore, it is assumed that this is an example of an NPIU that is widely transported.

4.2.2 Transportation Information and Doses

Summarized below is information for mineral ores and products that are NPIU. Transport and dose information is summarized for tantalum, rare earth, and zircon/heavy minerals sands. Information provided below includes mass percent of uranium and thorium, activity concentrations, exposure information and measured or estimated doses associated with truck drivers.

4.2.2.1 Tantalum

Measured gamma radiation dose rates. In the TIC study, gamma dose rates were measured for 59 tantalum raw material shipments. There were nine combinations of geometry and distance for the measurement locations. Table 14 summarizes the dose rates attributed to the tantalum raw material shipments with gamma radiation surveys. The attributed amount was calculated by subtracting the baseline gamma radiation level from the gamma radiation levels measured with the loaded container (TIC 2007).

Table 14. Summary of measured attributable dose rates (µSv h^{-1}) by distance and geometry relative to the container

Statistic	Side			Corner			End		
	Contact	1 m	3 m	Contact	1 m	3 m	Contact	1 m	3 m
Slag shipments (n = 20)									
Median	3.5	1.5	0.5	3.0	1.1	0.4	2.0	0.8	0.2
Mean	4.7	1.9	0.6	6.1	1.3	0.4	2.6	0.9	0.3
Maximum	16.5	5.9	1.5	26.2	4.1	1.3	9.9	3.9	0.7
Tantalite shipments (n - 37)									
Median	2.0	0.8	0.3	1.9	0.7	0.3	1.3	0.5	0.2
Mean	2.4	0.9	0.3	2.0	0.8	0.3	1.6	0.6	0.2
Maximum	6.6	3.0	1.1	6.2	2.6	0.9	5.4	2.1	0.6

Source: TIC 2007

The measured gamma dose rates around the shipments were variable due to the range of concentrations and loading configurations between shipments. The mean contact dose rate measurements for tantalite shipments ranged between 1.6 and 2.4 µSv h^{-1}, depending on location.

The mean contact exposure rates are higher for slag and range from 2.6 to 6.1 µSv h^{-1} depending on location. The higher exposure rates for slag shipments compared to the tantalite shipments are due to: (1) slag materials have higher total activity concentrations, and (2) gamma exposure rate per Bq g^{-1} of ^{232}Th is higher than that for ^{238}U, and the slag materials have a higher proportion of ^{232}Th to ^{238}U compared to the tantalite materials (TIC 2007).

Table 15 summarizes the measured exposure or dose rates, and estimated doses to truck drivers transporting tantalite concentrates and slag materials based on the TIC study (TIC 2007).

Modeled gamma dose rates. The Microshield model (Grove Software 2005) was used to estimate gamma dose rates for tantalum material transport, in general, based on information from the sample of shipments. All shipments were assumed to have the most fully loaded configuration (i.e., 1.5 tiers, maximum load). This was considered conservative compared to the measured exposure rates. However, the approach was considered reproducible and could be applied to varying concentrations of material, and calculation of exposure rates at locations and geometries not measured during the surveys (TIC 2007).

Table 15. Summary of truck driver exposure or dose rates from transport of tantalite concentration and slag

Receptor scenario	Tantalite concentrate ($Bq\ g^{-1}$)	Dose rate @ 3 m ($\mu Sv\ h^{-1}$)	Comments
Truck driver	4.5–68.1 U Avg.: 16.4 U 0.2–11.1 Th Avg.: 1.3 Th Total avg. (U + Th) = 17.7	Truck sides, mean range: 0.2–0.3 Max: 1.1	Measured exposure rates, estimated annual dose (TIC 2007)

Receptor scenario	Slag (by-product of [tin] smelting) concentration ($Bq\ g^{-1}$)	Dose rate @ 3 m ($\mu Sv\ h^{-1}$)	Comments
Truck driver	2.4–92.2 U avg.: 18.8 1.8–27.8 Th Avg.: 6.5 Th Total avg. (U + Th) = 25.3	Truck sides, mean range: 0.3–0.6 Max: 1.5	Measured exposure rates, estimated annual dose (TIC 2007)

Table 16 summarizes the predicted shipment dose rates using measured uranium and thorium concentrations.

Table 16. Summary of predicted dose rates ($\mu Sv\ h^{-1}$) for shipments with measured concentrations

Statistic	Side			Corner			End		
	Contact	1 m	3 m	Contact	1 m	3 m	Contact	1 m	3 m
Slag Shipments (n=22)									
Median	4.0	2.0	0.7	3.8	1.7	0.6	4.8	1.5	0.3
Mean	6.9	3.5	1.1	6.7	3.0	0.9	7.7	2.6	0.5
Maximum	18.9	9.6	3.0	18.9	8.3	2.5	18.9	7.3	1.5
Tantalite Shipments (n=45)									
Median	3.6	2.0	0.6	3.6	1.7	0.5	4.0	1.5	0.3
Mean	4.6	2.5	0.8	4.5	2.1	0.7	5.2	1.9	0.4
Maximum	20.2	10.7	3.6	19.5	9.2	3.0	23.4	8.2	1.6

Source: TIC 2007

Doses from transport activities. Shipments of tantalum raw materials vary based on the type of material and packaging technique used by the shipper. The standard method of shipping tantalite is in drums on pallets in either sea-land containers or trailers, while slags are typically shipped in 1 ton bags in sea-land containers (TIC 2007).

The maximum load for a sea-land container was assumed to consist of a full bottom tier and a half-full 2nd tier. The 2nd tier was assumed to be half the width of the 1st tier but was the entire length of the sea-land container. It was assumed that the truck driver had 3 trips per month (36 trips/year), and the exposure duration with the truck loaded was 10 hr per trip (TIC 2007). The gamma dose rate factor used assumed the distance of 3 m for the short side of the sea-land container. Table 17 summarizes the upper 95th percentile dose and mean dose calculated in the probabilistic trials arising from the variation in radioactivity content between shipments.

Table 17. Summary of annual doses for truck drivers during normal transport activities

Receptor scenario	Slag transport (mSv) 95th percentile (mean dose)	Tantalite transport (mSv) 95th percentile (mean dose)
Transport worker-truck driver	0.31 (0.24)	0.19 (0.16)

Source: TIC 2007

4.2.2.2 Rare earth materials

In the U.S., a person is exempt from license requirements if that person receives, possesses, uses, or transfers rare earth materials and compounds, mixtures, and products containing not more than 0.25% by weight thorium, uranium, or any combination of these [10 CFR 40.13 (c)(1)(vi)]. If it is assumed that 0.25% by weight of a rare earth product is ^{232}Th and ^{228}Th in equilibrium, the activity concentration of ^{232}Th and ^{228}Th would be about 10 Bq g^{-1} of each (NRC 2001).

As mentioned earlier, rare earths are constituents of a number of minerals, but only a few are recovered for commercial production. A variety of rare earth products are available; these include concentrates, individual and mixed compounds, and pure and alloyed metals (NRC 2001).Based on NUREG-1717, lower grade rare earth products, such as bastnasite and cerium concentrates are more likely to contain thorium, whereas higher grade products contain small or trace amounts of thorium.

A radiation survey was conducted by Molycorp on a truck load containing 3 drums of bastnasite concentrate and 14 pallets of cerium concentrate (NRC 2001). Inside the loaded trailer, the exposure rate readings, next to the drums of bastnasite concentrate and between the pallets of cerium concentrate, were about 0.2 and 0.4 mR/hr, respectively. Exposure rate measurements, taken in the truck cab and outside of the loaded trailer, ranged from 0.01 to 0.02 mR h^{-1} (including background).

Dose rates in the truck cab were estimated assuming 14 pallets (1,350 kg/pallet) of cerium concentrate (0.25% Th) and 3 drums of bastnasite concentrate (0.1% Th) with in-truck exposure rates of 0.01 to 0.02 mR h^{-1}. Natural background was assumed to be about 0.01 mR h^{-1}; therefore, the exposure rate is assumed to be 0.01 mR h^{-1}. Further, it was assumed that the truck driver was exposed for about 50 hr with an estimated effective dose equivalent (EDE) of 0.005 mSv per trip. If this driver made 30 similar trips across the U.S. annually, the estimated annual EDE would be 0.2 mSv (NRC 2001).

4.2.2.3 Zircon and heavy mineral sand concentrates

Four sources of information were used to evaluate the transport characteristics and dose associated with zircon and heavy mineral sand products: the Calytrix study (2007), NUREG-1717 (2001), the Health Protection Agency evaluation of doses associated with the transport of zircon flour (Hughes 2008), and the Selby et al. (2002) study. Based on these studies, the transport characteristics of these materials and associated doses to truck drivers are summarized below.

Calytrix Study (2008). In 2008, a study was conducted to evaluate the transport of heavy mineral sands in Australia. The main purpose of the study was to determine if the exemption of the transport of material in bulk in the mineral sands industry was justified and if the factor of 10 used for "natural materials" is appropriate**.** Multiple stages of transport of concentrates, intermediate, and final products were studied. Radiation exposure information was obtained for 16 routes; however, our interest focuses on the following transport routes:

- Transport of "primary" concentrate to a "secondary" concentrator, two routes by road
- Transport of heavy mineral concentrate (HMC) from mine site to separation plants by road
- Transport of final products from a separation plant to a wharf by road

The parameters associated with the routes evaluated are shown in Table 18. The exposure rate readings are shown in Table 19. Monitoring of potential exposure to the external gamma-radiation was carried out with the following equipment: Radiation Alert "inspector" instrument, Exploranium "identifier" instrument, Canary II Model 4080 portable electronic dosimeters, and TLD badges.

Monitoring of potential internal exposure due to the presence of airborne dust was carried out using Aircheck 2000 dust pumps and dust filters. Dust filters were analyzed for long-lived alpha activity.

Table 18. Parameters associated with road transport routes

Route No.	Material and mode of transport	No of workers monitored	Distance of trip (km)	Duration (hr) (carrying product)	No. trips/ shift	Total working hr yr^{-1}	Comments
Transport of heavy mineral concentration (HMC) between mine sites and processing plants							
1	HMC—road	8	200	2.5	2	1,200	
2	HMC—road	3	15	0.5	8	1,200	Driver also loads truck.
4	HMC tailings—road	3	C → B B → C	4		500	
5	HMC—road	5	70	1.5	3–4	2,000	
6	HMC—road		30–40	0.5	9–10	1,000	
7	HMC—road, tails return	5	110	2	2	1,100	
8	HMC—road, tails return	6/4	140	3/7	2	2,000	
9	HMC—road	4	160	2.5	2	1,400	
Transport of minerals from processing plants to ports							
11	Zircon—road	4		~ 0.5		500	
11	Ilmenite/synthetic rutile—road	4		~ 0.5		500	
12	Zircon—road		100	2		600	
13	Ilmenite/synthetic rutile—road	2 trucks	60	1		500	

Table 19. Exposure rate and doses associated with road transport routes

Route No.	Material and mode of transport	Bq g^{-1} in the material	Highest dose rate (μSv/yr)	Highest dose rate (nSv h^{-1})
1	HMC—road	2.0	107	89
2	HMC—road	4.1	367	306
4	HMC—road/tailings	8.0	294	588
5	HMC—road	1.0	220 (driver)	110 (driver)
6	HMC—road	1.5	151	151
7	HMC—road/tails return	3.9/8.0	604	549
8	HMC—road/tails return	1.9/6.0	387 (driver)	194 (driver)
9	HMC—road	1.6/3.0 ~2.3	227	162
11	Zircon—road	4.1	52 (driver)	104 (driver)
11	Ilmenite/synthetic rutile—road	1.8	50 (driver)	100 (driver)
12	Zircon—road	3.8	59	98
13	Ilmenite/synthetic rutile—road	1.0	54 (driver)	108 (driver)

As shown in Table 19, the HMC activity concentrations ranged between 1 and 4 Bq g^{-1} and the highest annual dose ranged between 0.1 and 0.37 mSv. For the HMC tailings, the activity concentrations ranged between 6 and 8 Bq g^{-1} and the annual dose ranged between 0.3 and 0.6 mSv. The zircon activity concentration ranged between 3.8 and 4.1 Bq g^{-1} and the annual dose ranged between 0.05 and 0.06 mSv. The ilmenite/synthetic rutile activity concentration ranged between 1 and 2 Bq g^{-1} and the annual dose was estimated to be about 0.05 mSv.

Other zircon product studies. In addition to the Calytrix study, measured exposure rates and estimated exposure and dose rates associated with the handling and transport of zircon sands or zircon flour were conducted in earlier evaluations, as described in NUREG-1717. Measurements made are shown below in Table 20. In NUREG-1717, doses were estimated using Microshield and assuming that 48 pallets (50 41-kg bags per pallet) of 0.05% by weight uranium and thorium in zircon flour were transported with an exposure duration of 24 hr to transport 1 load and 25 trips per year (600 hr $year^{-1}$) by the same driver. Based on these assumptions, the estimated annual dose to the truck driver was estimated to be 0.06 mSv.

Doses were also estimated using Microshield by the Health Protection Agency, Radiation Protection Division (Hughes 2008). It was assumed that 20 tons of zircon flour was transported with the following radionuclide concentrations: 3 Bq g^{-1} ^{238}U, 0.15 Bq g^{-1} ^{235}U, and 0.6 Bq g^{-1} ^{232}Th. The driver was assumed to be 1 m from the load surface and to have an annual driving time of 600 hr, resulting in an annual dose of about 0.18 mSv.

In a study conducted by Selby et al. (2002), doses were measured rather than modeled and addressed the transport of large quantities of zircon from producers in South Africa to customers in Europe. For the transport of bulk zircon, a total of 50,000 tons of zircon is transported by road to a bagging facility 22 km from the production plant. A total of 1,250 truckloads are moved annually. Each driver hauled on average 208 truckloads per year. The total exposure time was 92 hr per year with a source to receptor distance of about 1.8 m from the bulkhead and 25 mm of steel between the driver and source. The annual dose to the truck driver of the bulk zircon was 0.02 mSv.

In the transport of bagged zircon, a driver and helper were exposed in the driver's cabin during the 2 hr transport to a container depot. Bags were packaged as 1 or 2 ton bags, depending on consignment specifications. A total consignment typically consisted of 200 to 500 tons of material. Thirty consignments were transported per year. A conservative average distance of 1 m from the sources was assumed. The estimated annual exposure time was 60 hr. The annual dose to truck driver and helper of the bagged zircon was 0.02 mSv (Selby et al. 2002).

Table 20 summarizes uranium and thorium concentrations, measured or estimated exposure rates, and estimated annual doses to truck drivers transporting/hauling heavy mineral concentrates, zircon sands, zircon flour, and other zircon-related products (e.g., ilmenite/synthetic rutile).

Table 20. Truck driver exposure rates and estimated doses associated with HMC and zircon products

Heavy mineral concentrates and other products, Bq g^{-1} in material	Zircon sands Bq g^{-1} or ppm	Zircon flour Bq g^{-1} or wt %	Exposure or dose rates	Estimated annual doses (µSv)	Sources
		0.05% U + Th 8.5 Bq g^{-1} U 0.65 Bq g^{-1} Th	1E-4 µSv per trip (estimated)	60 µSv (0.06 mSv)	NRC 2001
1–8 (See Table 19.)			89–588 nSv h^{-1} 0.09–0.6 µSv h^{-1} (measured)	50–604 µSv (0.05–0.6 mSv)	Calytrix 2008
		3 Bq/g^{-1} ^{238}U 0.15 Bq g^{-1} ^{235}U 0.6 Bq g^{-1} ^{232}Th	0.3 µSv h^{-1} (estimated)	180 µSv (0.18 mSv)	Hughes 2008
	3.1–4.4 Bq g^{-1} ^{238}U 0.4–0.8 Bq g^{-1} ^{232}Th		Bulk: 0.23 µSv h^{-1} Bagged: 0.05 µSv h^{-1} (measured)	Bulk: 21 µSv (0.02 mSv) Bagged: 20 µSv (0.02 mSv)	Selby et al. 2002

4.2.3 NPIU—Normalized Transportation Activity Concentrations Based on an Annual Dose of 10 µSv

The NPIU mineral ores and mineral products dominated the 1 to 10 Bq g^{-1} category, though the tantalite concentrate had activity concentrations greater than 10 Bq g^{-1}. The annual estimated doses for the NPIU ranged between 0.02 and 0.6 mSv; however, the exposure durations widely varied. Normalizing the doses to an annual exposure duration of 400 hr, the estimated doses ranged between 0.04 and 0.2 mSv. Using the normalized doses and assuming an annual dose of 10 µSv, the activity concentrations ranged between 0.2 and 13 Bq g^{-1}. As shown in Table 21, normalizing the dose to account for a 400 hr annual exposure duration resulted in derived activity concentrations, based on the measured or estimated doses, to be close to or within the range of 1 to 10 Bq g^{-1}.

Table 21. NPIU—activity concentrations, exposure durations, doses and normalization to annual dose of 10 µSv for comparison to exemption values

Materials (NPIU)	Uranium conc. (Bq g^{-1})	Thorium conc. (Bq g^{-1})	Exposure duration (hr)	Estimated annual doses (mSv)	Normalized annual doses based on 400 hr exposure duration (mSv)	Derived U+Th activity conc. Bq g^{-1} to 10 uSv (0.01 mSv) (corrected for 400 hr exposure duration)
Tantalite concentrate (TIC 2007)	16.4	1.3	360	Mean: 0.16	0.18	1.0
Bastnasite concentrate Cerium concentrate (NRC 2001)	0.5	0.8–4 10	1,500	0.2	0.05	0.2–0.8 BC only[a] (0.2–2.7)[b]
Heavy mineral HMC Zircon Ilmenite/synthetic rutile HMC tailings (Calytrix 2008)	 0.6 3.0 0.2 1.7	 1.6 0.9 1.2 5.1	1,000–2,000 500–600 500 500–2,000	 0.1–0.37 0.05–0.06 0.05 0.3–0.6	 0.04–0.07 0.04 0.04 0.24–0.12	 0.3–0.6 1 0.4 0.3–0.6
Zircon flour a: NRC 2001 b: Hughes 2008	a. 8.5 U b. 3 ^{238}U, 0.15 ^{235}U	a. 0.65 Th b. 0.6 ^{232}Th	a. 600 b. 600	a. 0.06 b. 0.18	a. 0.04 b. 0.12	a. 2.3 b. 0.3
Zircon sand (Selby 2002)	3.1–4.4 ^{238}U	0.4–0.8 ^{232}Th	Bulk: 92 Bagged: 60	0.02 (Bulk/Bag)	Bulk: 0.09 Bagged: 0.13	Bulk: 0.4–0.6 Bagged: 0.3–0.4

[a]Derived activity concentration includes only uranium and thorium concentrations associated with bastnasite concentrate (BC).

[b]Derived activity concentration includes uranium and thorium concentrations associated with both bastnasite concentrate and cerium concentrate.

4.3 COMPARISON OF RESULTS

4.3.1 Activity Concentrations and Dose

In the previous sections, ore production, transportation modes, weight percent uranium and thorium (where applicable), activity concentrations, exposure rates, exposure durations, and associated doses associated with the transport of uranium ores, alternate feed materials and selected ores and products were explored. Table 22 summarizes by activity category: (1) <1 Bq g^{-1}, (2) 1 to 10 Bq g^{-1}, and (3) >10 1 Bq g^{-1}, the doses associated with the transport of ores and products. Vanadium pentoxide, rare earth ore and bastnasite concentrate had uranium activity concentrations less than 1 Bq g^{-1}. Mineral ores and mineral products dominated the 1 to 10 Bq g^{-1} category; however, contaminated soils, which are used as alternate feed residues, also fit into this category. There are other alternate feed materials that have average activity concentrations close to 10 Bq g^{-1} (e.g., other contaminated soils and monazite sands). The annual doses associated with the 1 to 10 Bq g^{-1} category ranged between 0.02 mSv to 0.6 mSv. Annual exposure durations ranged from 60 to 2000 hr. The primary transportation modes were end dump trailers and semi-trailers.

Table 22. Activity concentrations, exposure durations, doses and comparison to exemption values

Concentration category	PIU or NPIU	Transport mode	Uranium conc. (Bq g^{-1})	Thorium conc. (Bq g^{-1})	Exposure duration hr	Estimated annual doses (mSv)	U+Th activity conc. (Bq g^{-1}) for 10 µSv (uncorrected for exposure duration)	Derived U+Th activity conc. (Bq g^{-1}) to 10 µSv (corrected for 400 hr exposure duration)
<1 Bq g^{-1}								
Vanadium (vanadium pentoxide)	PIU	Semi-trailer	0.3		144	0.07	0.04	0.02
Rare earth ore (bastnasite ore)	NPIU		0.3	1				
1–10 Bq g^{-1}								
Bastnasite concentrate Cerium concentrate (NRC 2001)	NPIU	Semi-trailer (domestic) Sea train (international)	0.5	0.8–4 10	1,500	0.2	0.07 to 0.7	0.2 to 0.8 BC only[a] (0.2 to 2.7)[b]
Heavy mineral **HMC** **Zircon** **Ilmenite/synthetic rutile** **HMC tailings (Calytrix 2008)**	NPIU	End dump trailers*	0.6 3.0 0.2 1.7	1.6 0.9 1.2 5.1	1,000–2,000 500–600 500 500–2,000	0.1–0.37 0.05–0.06 0.05 0.3–.6	0.06–0.2 0.7 –0.8 0.3 0.1–0.2	0.3–0.6 1 0.4 0.3–0.6
Zircon flour **a: NRC 2001** **b: Hughes 2008**	NPIU	Semi-trailer	a. 8.5 U b. 3 ^{238}U, 0.15 ^{235}U	a. 0.65 Th b. 0.6 ^{232}Th	a. 600 b. 600	a. 0.06 b. 0.18	a. 1.5 b. 0.2	a. 2.3 b. 0.3
Zircon sand	NPIU	Bulk: semi-trailer Bagged: flat bed trailer truck	3.1–4.4 ^{238}U	0.4–0.8 ^{232}Th	Bulk: 92 Bagged: 60	Bulk/Bagged: 0.02	1.8–2.6	Bulk: 0.4-0.6 Bagged: 0.3-0.4

Table 22. (continued)

Concentration category	PIU or NPIU	Transport mode	Uranium conc. (Bq g^{-1})	Thorium conc. (Bq g^{-1})	Exposure duration hr	Estimated annual doses (mSv)	U + Th activity conc. (Bq g^{-1}) for 10 µSv (uncorrected for exposure duration)	Derived U +Th activity conc. (Bq g^{-1}) to 10 µSv (corrected for 400 hr exposure duration
>10 Bq g^{-1}								
Copper concentrate (BHP Billiton 2009)	PIU/ NPIU[c]	Drums intermodal	25–50		800	0.8 (est.)	0.3–0.6	0.6–1.3
Tantalite concentrate (TIC 2007)	NPIU	Semi-trailer	16.4	1.3	360	Mean: 0.16	1.1	1
Rare earth lead sulfide residues (Johnson 2002)	NPIU/ PIU[c]	Lined end dump trucks	38		216	0.1	3.8	2
Low grade uranium ore (Charette 2008, 2009)	PIU	Ore truck	38–50		Mean: 224	2007: 0.02 2008: 0.07	2007: 19–25 2008: 5–7	2007: 11–14 2008: 3–4
Uranium ore (Cain 2009)	PIU	Ore truck	63		408	0.052	12	12
Tantalum ore residue (Eves 2009)	NPIU/ PIU[c]	Lined intermodal	188	10	Short: 18 Longer: 35	Short trip: 0.01–0.04 Longer trip: 0.02–0.07	Short: 50–198 Long: 28–99	Short: 2–9 Long: 2.5–9

[a]Derived activity concentration includes only uranium and thorium concentrations associated with bastnasite concentrate (BC).
[b]Derived activity concentrations include uranium and thorium concentrations associated with both bastnasite concentrate and cerium concentrates.
[c]These products transition between the PIU and NPIU designation.

As expected, most uranium ore had activity concentrations greater than 10 Bq g^{-1}. However, copper concentrate, tantalite concentrates, rare earth lead sulfide residues, and tantalum ore residues also had activity concentrations greater than 10 Bq g^{-1}. The annual doses ranged between 0.01 and 0.8 mSv. Annual exposure durations ranged between 18 and 800 hr. The primary transportation modes were ore trucks, semi-trailers, and intermodal freight containers.

4.3.2 Transportation Activity Concentrations Normalized to an Annual Dose of 10 µSv

Table 22 shows activity concentrations that would result in an annual dose of 10 µSv, the limiting dose for the exemption values of *TS-R-1*. The exemption values for U nat. and Th nat. were based on a bulk transport and annual exposure duration of 400 hr. Normalizing the doses to an annual exposure duration of 400 hr, the doses for the 1 to 10 Bq g^{-1} category ranged from 0.04 to 0.2 mSv and the derived activity concentrations ranged between 0.2 and 2.7 Bq g^{-1}. The derived activity concentrations based on the normalized doses were within the exemption values if Paragraph 107(e) is revised to apply to all NORM materials.

Uranium ores, some alternate feed materials (rare earth and tantalum residues), and some mineral concentrates had activity concentrations > 10 Bq g^{-1}. Normalizing the doses based on an annual exposure duration of 400 hr, the estimated doses for the > 10 Bq g^{-1} category ranged between 0.04 and 0.9 mSv. The derived activity concentrations that would result in an annual dose of 10 µSv ranged from 0.6 to 14 Bq g^{-1}.

Derived activity concentrations that resulted in an annual dose of 10 µSv (based on normalized doses) ranged from 0.2 and 14 Bq g^{-1} regardless of PIU.

4.3.3 Estimated Doses Based on 10 Bq g^{-1} Exemption Concentration

Another approach to evaluating the dose and actual activity concentration data is to determine the doses that would result if the activity concentration was 10 Bq g^{-1}. Multiplying by a ratio of the normalized doses (annual exposure duration of 400 hr) over the actual activity concentrations, the estimated doses associated with 10 Bq g^{-1} for the ores and products, both PIU and NPIU, ranged from 0.01 to 0.4 mSv. An average annual dose was estimated to be about 0.1 mSv. These doses are considerably lower than the IAEA “practical dose constraint” of 1 mSv and within the range of the “prudent” dose constraint of 0.1 mSv (ICRP 2007)

4.4 PRODUCTION IMPACT

There have been concerns that removal of the intended for use clause, which excluded PIU materials in Paragraph 107(e), could potentially result in large amounts of material transported with exemption status without the proper radiological controls. Based on this analysis, the amount of material that could be impacted by removal of this exemption would not be significant compared to the material currently being transported with exemption status. In fact, the only PIU products identified in this study, with an activity concentration between 1 and 10 Bq g^{-1}, were selected alternate feed materials (contaminated soils). As shown in Appendix B, the amount of material that could be processed as alternate feed and that has an activity concentration less than 10 Bq g^{-1} is about 294,000 tons (Ashland and Maywood soils) (White Mesa 2007).

Other materials that could be impacted by removal of the PIU clause would be ores and products such as copper and vanadium that are coproduced or produced as a by-product of uranium ore processing. If the uranium concentrations could be reduced in some of these products, the amount of material that could be transported in accordance with the exemption would be greater.

4.5 CONCLUSIONS

In this section the PIU provision was evaluated to determine whether there was a valid radiation protection basis and whether the PIU restriction represented a bias against material previously processed or intended for use of radionuclides. In making this evaluation, the focus was primarily on

uranium and mineral ores that contained uranium in order to compare doses between ores based on their intended use in the fuel cycle and non-fuel cycle. Of particular interest were products that transitioned in and out of the regulations based on their PIU. Based on evaluation of the information obtained for this study, some observations can be made:

- The NPIU mineral ores and products dominated the 1 to 10 Bq g-1 range. However, there were some alternate feed materials (PIU) that had activity concentrations within the 1 and 10 Bq g-1 range. Copper and vanadium, co-mined ores (PIU), had activity concentrations close to the 1 to 10 Bq g-1 category.
- The greater than 10 Bq g-1 category primarily contained ores and products intended for use of radionuclides (PIU). There were also a few NPIU products within this category: tantalite, and copper concentrate.
- Derived activity concentrations that resulted in an annual dose of 10 µSv (based on normalized doses) ranged between 0.2 and 14 Bq g-1 regardless of PIU. Normalized doses that resulted from an activity concentration of 10 Bq g-1 ranged from 0.01 to 0.4 mSv, with an average annual dose of about 0.1 mSv. These doses are considerably lower than the IAEA "practical dose constraint" of 1 mSv and within the range of the "prudent" dose constraint of 0.1 mSv (ICRP 2007).
- There are ores and ore concentrates such as copper and vanadium, which are co-mined or produced as a by-product of uranium ore processing. There may be other ores that come from multielement mines where the uranium concentrations are within the 1 to 10 Bq g-1 range. These ores and alternate feed materials are most impacted by the PIU exemption.

The PIU restriction implies that past or future extraction of radionuclides from a material either results in higher transport doses from the same exposure scenarios or that these materials are transported in a manner resulting in higher doses (e.g., package type or exposure distance). Neither situation appears to be occurring. There does not appear to be a sound technical basis for maintaining the intended use distinction; therefore, PIU and NPIU should be exempt by Paragraph 107(e) since doses are similar regardless of intended use. As stated in an earlier paper (Rawl, Leggett, and Cook 2007), the PIU restriction appears to represent a bias against material used in the nuclear fuel cycle, and it may reinforce public misconceptions concerning risk associated with nuclear power.

Though not evaluated in this study, another scenario may exist whereby uranium and thorium ore and concentrates are regulated but the final/end products are not regulated (e.g., microwave magnetrons and TIG welding rods). These products contain thorium, which may have greater activity concentrations as compared to the original ore, and in the case of the welding rods, also present an airborne hazard. Thus, this scenario gives more reason to extend the 10x exemption to all NORM materials with an activity concentration within 1 to 10 Bq g^{-1} regardless of PIU.

5. DOSE JUSTIFICATION FOR EXEMPT MATERIALS AND LOW SPECIFIC ACTIVITY MATERIALS

In Section 3, the inconsistencies in the derivation of the exempt activity concentration values, specifically evaluation of the 10x exemption and the PIU clause in *TS-R-1*, Paragraph 107(e) were evaluated. It was found that the 10x provision is consistent with the IAEA practice of relaxing radionuclide exemption concentrations within cautious bounds to achieve a balance between practical issues and radiological concerns. It was also found that the PIU provision was not risk informed and should be based on dose implications, not on the PIU of the material being transported.

Section 4 examined doses associated with the transport of materials that either had PIU of radionuclides or did not have PIU of radionuclides. Doses associated with the transport of material that would be exempt under Paragraph 107(e) and materials that would be transported as LSA-1 were collected. As expected, the doses were proportional to the activity concentration (assuming similar configurations) and not dependent on the PIU of the material.

Based on the evaluation of doses due to transport of low-level NORM, it is suggested that the transport regulations should be revised so that all natural materials (regardless of PIU and provided that the ten times limit of Paragraph 107(e) is met) are subject to the same exemption provisions. This approach requires a supporting revision to the material specification applicable to LSA-I materials in *TS-R-1* Paragraph 409(a)(i). This supporting revision would clarify that all uranium and thorium ores and concentrates, and other ores containing NORM, regardless of their PIU, are included in the LSA-I category if they exceed the ten times provision of Paragraph 107(e).

6. TREATMENT OF PROGENY FOR A_1/A_2 AND EXEMPT CONCENTRATION VALUES

Another U.S. research objective was to evaluate the dose implications resulting from the different treatment of progeny associated with the A_1/A_2 values and the exempt activity concentration values for radioactive materials. To address this objective, an evaluation of how progeny were included in the derivation of the A_1/A_2 and exemption values was conducted. Specific inconsistencies of how the progeny were addressed in the derivation of these values are highlighted, and the potential impact on dose is evaluated.

6.1 COMPARISON OF PROGENY INCLUSION IN CALCULATING A_1/A_2 AND EXEMPTION VALUES

Radionuclide-specific "activity concentrations for exempt material" and "activity limits for exempt consignments" are listed in Table 2 of *TS-R-1* (IAEA 2009), which identifies materials and consignments that are not subject to the transport regulations. Table 2 also provides activity limits (A_1 and A_2 values) for the allowable content of individual radionuclides in Type A (nonaccident resistant) packages.

The A_1 and A_2 values are calculated using the "Q-system." The details of these calculations can be found in the *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material* (IAEA 2008). A_1 and A_2 values are based on consideration of potential modes and levels of exposure to persons in the vicinity of a Type A package involved in a transport accident. The Q-system assumes a maximum transport time of 50 d, and thus, radioactive decay products with half-lives less than 10 d are assumed to be in equilibrium with their longer lived parents. Progeny radionuclides with half-lives less than 10 d are assumed to be in secular equilibrium with the longer lived parent, and the daughter's contribution to each Q value is summed with that of the parent. This provides a means of accounting for progeny with branching fractions less than one; for example, ^{137m}Ba is produced in 0.946 of the decays of its parent, ^{137}Cs.

In contrast to the Q-system, the methodology underlying the exemption values in the IAEA Basic Safety Standards (IAEA 1994) and *TS-R-1* did not include a uniform rule for inclusion or exclusion of radioactive progeny of the radionuclide of interest. Rather, an effort was made to include chain members that may actually be present in significant quantities relative to that of the parent in realistic situations. Relatively short-lived radioactive progeny were assumed to be in secular equilibrium with their parents in cases where this seemed consistent with the timescales of the exposure scenarios (Harvey et al. 1993). Long-lived radioactive progeny were included in some but not all cases. For selected decay series occurring in nature, including the ^{238}U chain and the ^{232}Th chain, the exemption value is based on the assumption that the parent is in secular equilibrium with all radioactive progeny, regardless of half-life.

6.2 INCONSISTENCIES REGARDING INCLUSION OF DECAY CHAINS AND IMPACT ON DOSES

Many of the radionuclides included in Table 2 of *TS-R-1* have radioactive decay products (progeny) that should be taken into account when estimating dose from a source containing the parent radionuclide. Assumptions regarding radioactive progeny made in the derivation of the exemption values are not always consistent with the assumptions used in calculating the A_1 and A_2 values for the same radionuclide.

Paragraph 404 of *TS-R-1* states:

> In the calculations of A_1 and A_2 for a radionuclide not in Table 2, a single radioactive decay chain in which the radionuclides are present in their naturally occurring proportions,

> and in which no progeny 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 A_1 or A_2 value to be applied shall be that corresponding to the parent nuclide of that chain. 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.

No similar discussion regarding the exemption values is presented, presumably because no further calculation of these values is indicated. Table 2 does include a series of footnotes with footnotes (a) and (b) providing information regarding decay chains. Footnote (a) identifies those nuclides in the table for which the A_1 and A_2 values include the contributions from daughter radionuclides with half-lives of less than 10 d, and footnote (b) identifies those parent nuclides and their progeny that are considered to be in secular equilibrium in calculating the exemption values. As discussed, the two footnotes differ with no explanation.

The concept of secular equilibrium is the basis of footnote (b), but no definition is provided in the document. Secular equilibrium can only occur in a radioactive decay chain if the half-life of the daughter radionuclide B is much shorter than the half-life of the parent radionuclide A. In such a situation, the decay rate of A, and hence, the production rate of B is approximately constant, because the half-life of A is very long compared to the time period being considered. The International Union of Pure and Applied Chemistry defines secular equilibrium as a "radioactive equilibrium where the half life of the precursor isotope is so long that the change of its activity can be ignored during the period of interest and all activities remain constant." These definitions involve a consideration of a period of interest which is unstated in footnote (b).

The basis for the exemption values appears to be in SRS No. 44 entitled *Derivation of Activity Concentration Values for Exclusion, Exemption and Clearance* (IAEA 2005b). The activity level of the progeny assumed in the calculations is presented in Appendix II which consists of only a table but presumably is based on the discussion of Sec. 3.1.2 (IAEA 2005b).

6.2.1 Selected Cases of Inconsistency

Below are selected cases of inconsistency regarding footnotes (a) and (b) of Table 2 in TS-R-1. To evaluate these inconsistencies, the decay chain information of ICRP *Publication 107* is used. ICPR *Publication 107* supersedes *ICRP Publication 38,* which underlies current IAEA documents including the A_1/A_2 values. Presumably, future effort by the agency will be based on ICRP *Publication 107.*

Zircon-97 **Chain:**

Nb-97m is listed in footnote (a) but not in (b). The decay chain is:

Zr-97 Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Nuclide	f2	Daughter Products Nuclide	f3	Nuclide	f4	Nuclide
1	Zr-97	16.744h	1.000E+00	Nb-97						
2	Nb-97	72.1m	1.000E+00	Mo-97						

Stable isotope(s) shown in yellow.

In *ICRP Publication 38*, 95% of ^{97}Zr decays to $^{97\,m}$Nb, which decays to ^{97}Nb. However, in *ICRP 107*, all ^{97}Zr decays to ^{97}Nb as apparently assumed in footnote (b).

Cerium-144 Chain:
Pr-144m is listed in footnote (a) but not in (b). This decay chain is:

Ce-144 Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Nuclide	f2	Nuclide	f3	Nuclide	f4	Nuclide
				Daughter Products						
1	Ce-144	284.91d	9.770E-03	Pr-144m	9.902E-01	Pr-144				
2	Pr-144m	7.2m	9.993E-01	Pr-144	7.000E-04	Nd-144				
3	Pr-144	17.28m	1.000E+00	Nd-144						
4	Nd-144	2.29E+15y	1.000E+00	Ce-140						

Stable isotope(s) shown in yellow.

Less than 1% of ^{144}Ce decays to $^{144\,m}$Pr, and footnote (b) does not list isotopes formed by small branching fractions. It is not stated what level branching is considered insignificant. This minor branch was listed in footnote (a).

Radon-222 **Chain:**
At-218 is listed in footnote (a) and not in (b). This decay chain is:

Rn-222 Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Nuclide	f2	Nuclide	f3	Nuclide	f4	Nuclide
				Daughter Products						
1	Rn-222	3.8235d	1.000E+00	Po-218						
2	Po-218	3.10m	9.998E-01	Pb-214	2.000E-04	At-218				
3	Pb-214	26.8m	1.000E+00	Bi-214						
4	At-218	1.5s	9.990E-01	Bi-214	1.000E-03	Rn-218				
5	Bi-214	19.9m	9.998E-01	Po-214	2.100E-04	Tl-210				
6	Rn-218	3.5E-2s	1.000E+00	Po-214						
7	Po-214	1.643E-4s	1.000E+00	Pb-210						
8	Tl-210	1.30m	1.000E+00	Pb-210						
9	Pb-210	22.20y	1.000E+00	Bi-210	1.900E-08	Hg-206				
10	Bi-210	5.013d	1.000E+00	Po-210	1.320E-06	Tl-206				
11	Hg-206	8.15m	1.000E+00	Tl-206						
12	Po-210	138.376d	1.000E+00	Pb-206						
13	Tl-206	4.200m	1.000E+00	Pb-206						

Stable isotope(s) shown in yellow.

At-218 was ignored in footnote (b) because of its low yield in the decay of ^{218}Po. The decay chain as defined in *ICRP 107* also includes ^{218}Rn and ^{210}Tl as short-lived daughter products of ^{222}Rn with small branching fractions.

Radon-223 **Chain:**
Po-211 is listed in footnote (a) but not in (b). This decay chain is:

Rn-223 Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Nuclide	f2	Nuclide	f3	Nuclide	f4	Nuclide
				Daughter Products						
1	Rn-223	24.3m	1.000E+00	Fr-223						
2	Fr-223	22.00m	1.000E+00	Ra-223	6.000E-05	At-219				
3	Ra-223	11.43d	1.000E+00	Rn-219						
4	At-219	56s	9.700E-01	Bi-215						
5	Rn-219	3.96s	1.000E+00	Po-215						
6	Bi-215	7.6m	1.000E+00	Po-215						
7	Po-215	1.781E-3s	1.000E+00	Pb-211						
8	Pb-211	36.1m	1.000E+00	Bi-211						
9	Bi-211	2.14m	9.972E-01	Tl-207	2.760E-03	Po-211				
10	Tl-207	4.77m	1.000E+00	Pb-207						
11	Po-211	0.516s	1.000E+00	Pb-207						

Stable isotope(s) shown in yellow.

Po-211 was ignored in footnote (b) because of its low yield in the decay of ^{211}Bi. *ICRP 107* includes the minor branch of ^{223}Fr that decays to ^{219}At.

Radium-226 Chain:
At-218 is listed in footnote (a) but not in (b). This decay chain is:

Ra-226 Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Nuclide	f2	Daughter Products Nuclide	f3	Nuclide	f4	Nuclide
1	Ra-226	1600y	1.000E+00	Rn-222						
2	Rn-222	3.8235d	1.000E+00	Po-218						
3	Po-218	3.10m	9.998E-01	Pb-214	2.000E-04	At-218				
4	Pb-214	26.8m	1.000E+00	Bi-214						
5	At-218	1.5s	9.990E-01	Bi-214	1.000E-03	Rn-218				
6	Bi-214	19.9m	9.998E-01	Po-214	2.100E-04	Tl-210				
7	Rn-218	3.5E-2s	1.000E+00	Po-214						
8	Po-214	1.643E-4s	1.000E+00	Pb-210						
9	Tl-210	1.30m	1.000E+00	Pb-210						
10	Pb-210	22.20y	1.000E+00	Bi-210	1.900E-08	Hg-206				
11	Bi-210	5.013d	1.000E+00	Po-210	1.320E-06	Tl-206				
12	Hg-206	8.15m	1.000E+00	Tl-206						
13	Po-210	138.376d	1.000E+00	Pb-206						
14	Tl-206	4.200m	1.000E+00	Pb-206						

Stable isotope(s) shown in yellow.

At-218 was ignored in footnote (b) because of its low yield in the decay of ^{218}Po. *ICRP 107* includes ^{218}Rn and ^{210}Tl as the short-lived members of the ^{226}Ra decay chain.

Thorium-234 Chain:
Pa-234 is listed in footnote (a) but not in (b). This decay chain is:

Th-234 Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Nuclide	f2	Daughter Products Nuclide	f3	Nuclide	f4	Nuclide
1	Th-234	24.10d	1.000E+00	Pa-234m						
2	Pa-234m	1.17m	1.600E-03	Pa-234	9.984E-01	U-234				
3	Pa-234	6.70h	1.000E+00	U-234						
4	U-234	2.455E+5y	1.000E+00	Th-230						
5	Th-230	7.538E+4y	1.000E+00	Ra-226						
6	Ra-226	1600y	1.000E+00	Rn-222						
7	Rn-222	3.8235d	1.000E+00	Po-218						
8	Po-218	3.10m	9.998E-01	Pb-214	2.000E-04	At-218				
9	Pb-214	26.8m	1.000E+00	Bi-214						
10	At-218	1.5s	9.990E-01	Bi-214	1.000E-03	Rn-218				
11	Bi-214	19.9m	9.998E-01	Po-214	2.100E-04	Tl-210				
12	Rn-218	3.5E-2s	1.000E+00	Po-214						
13	Po-214	1.643E-4s	1.000E+00	Pb-210						
14	Tl-210	1.30m	1.000E+00	Pb-210						
15	Pb-210	22.20y	1.000E+00	Bi-210	1.900E-08	Hg-206				
16	Bi-210	5.013d	1.000E+00	Po-210	1.320E-06	Tl-206				
17	Hg-206	8.15m	1.000E+00	Tl-206						
18	Po-210	138.376d	1.000E+00	Pb-206						
19	Tl-206	4.200m	1.000E+00	Pb-206						

Stable isotope(s) shown in yellow.

Pa-234 was ignored in footnote (b) because of its low yield in the decay of Pa-234m.

Americium-242m Chain*:*
Np-238 is listed in footnote (a) but not in (b). This decay chain is:

Am-242m Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Daughter Products: Nuclide	f2	Nuclide	f3	Nuclide	f4	Nuclide
1	Am-242m	141y	9.955E-01	Am-242	4.500E-03	Np-238				
2	Am-242	16.02h	8.270E-01	Cm-242	1.730E-01	Pu-242				
3	Np-238	2.117d	1.000E+00	Pu-238						
4	Cm-242	162.8d	1.000E+00	Pu-238	6.370E-08	SF				
5	Pu-242	3.75E+5y	1.000E+00	U-238	5.540E-06	SF				
6	Pu-238	87.7y	1.000E+00	U-234	1.850E-09	SF				
7	U-238	4.468E+9y	1.000E+00	Th-234	5.450E-07	SF				
8	Th-234	24.10d	1.000E+00	Pa-234m						
9	Pa-234m	1.17m	1.600E-03	Pa-234	9.984E-01	U-234				
10	Pa-234	6.70h	1.000E+00	U-234						
11	U-234	2.455E+5y	1.000E+00	Th-230						
12	Th-230	7.538E+4y	1.000E+00	Ra-226						
13	Ra-226	1600y	1.000E+00	Rn-222						
14	Rn-222	3.8235d	1.000E+00	Po-218						
15	Po-218	3.10m	9.998E-01	Pb-214	2.000E-04	At-218				
16	Pb-214	26.8m	1.000E+00	Bi-214						
17	At-218	1.5s	9.990E-01	Bi-214	1.000E-03	Rn-218				
18	Bi-214	19.9m	9.998E-01	Po-214	2.100E-04	Tl-210				
19	Rn-218	3.5E-2s	1.000E+00	Po-214						
20	Po-214	1.643E-4s	1.000E+00	Pb-210						
21	Tl-210	1.30m	1.000E+00	Pb-210						
22	Pb-210	22.20y	1.000E+00	Bi-210	1.900E-08	Hg-206				
23	Bi-210	5.013d	1.000E+00	Po-210	1.320E-06	Tl-206				
24	Hg-206	8.15m	1.000E+00	Tl-206						
25	Po-210	138.376d	1.000E+00	Pb-206						
26	Tl-206	4.200m	1.000E+00	Pb-206						

Stable isotope(s) shown in yellow.

Np-238 was ignored in footnote (b) because of its low yield in the decay of Am-242m.

Lead-210 Chain:
Po-210 is listed in footnote (b) but not in (a). This decay chain is:

Pb-210 Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Daughter Products: Nuclide	f2	Nuclide	f3	Nuclide	f4	Nuclide
1	Pb-210	22.20y	1.000E+00	Bi-210	1.900E-08	Hg-206				
2	Bi-210	5.013d	1.000E+00	Po-210	1.320E-06	Tl-206				
3	Hg-206	8.15m	1.000E+00	Tl-206						
4	Po-210	138.376d	1.000E+00	Pb-206						
5	Tl-206	4.200m	1.000E+00	Pb-206						

Stable isotope(s) shown in yellow.

Po-210 was not included in footnote (a) as its half-life is greater than 10 d. Footnote (a) only includes daughter products with half-lives less than 10 d. *ICRP 107* includes ^{206}Hg and ^{206}Tl as short-lived decay products of ^{210}Pb.

Radium-226 Chain:
Pb-210, ^{210}Bi, and ^{210}Po are listed in footnote (b) but not in (a). This chain is:

Ra-226 Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Daughter Products: Nuclide	f2	Nuclide	f3	Nuclide	f4	Nuclide
1	Ra-226	1600y	1.000E+00	Rn-222						
2	Rn-222	3.8235d	1.000E+00	Po-218						
3	Po-218	3.10m	9.998E-01	Pb-214	2.000E-04	At-218				
4	Pb-214	26.8m	1.000E+00	Bi-214						
5	At-218	1.5s	9.990E-01	Bi-214	1.000E-03	Rn-218				
6	Bi-214	19.9m	9.998E-01	Po-214	2.100E-04	Tl-210				
7	Rn-218	3.5E-2s	1.000E+00	Po-214						
8	Po-214	1.643E-4s	1.000E+00	Pb-210						
9	Tl-210	1.30m	1.000E+00	Pb-210						
10	Pb-210	22.20y	1.000E+00	Bi-210	1.900E-08	Hg-206				
11	Bi-210	5.013d	1.000E+00	Po-210	1.320E-06	Tl-206				
12	Hg-206	8.15m	1.000E+00	Tl-206						
13	Po-210	138.376d	1.000E+00	Pb-206						
14	Tl-206	4.200m	1.000E+00	Pb-206						

Stable isotope(s) shown in yellow.

Footnote (a) address the short-lived decay products of ^{226}Ra with half-lives less than 10 d. The half-life of ^{210}Pb is greater than 10 d, so that ^{210}Pb and its daughters are not included in footnote (a). The mixture rule is to be applied in shipping older ^{226}Ra sources (i.e., assuming a mixture of ^{226}Ra and ^{210}Pb).

It is anticipated that the impact on doses associated with inconsistent inclusion of progeny in deriving the quantities is minimal; nevertheless, it is important for the sake of consistency and for the user's information that the same physical information be used in these derivations and that the procedures be clearly stated. For example, the time period over which secular equilibrium is defined and level branching that is considered negligible should be stated. It is suggested that the decay chain information of ICRP *Publication 107* be used in future changes. If a nuclide is listed in footnote (b), then it need not be listed in footnote (a). All nuclides in (b) should be removed from (a) and their references in the table changed from (a) to (b). See Manabe et al. (2009) for some insight into the impact of the new nuclear decay data on inhalation dose coefficients applicable to workers. It should also be noted that updated information on the physical half-lives can have a significant impact on the calculated content of some waste streams subject to extensive hold up.

7. CONCLUSIONS

This report represents the U.S. contribution to the Safety of Transport of Naturally Occurring Radioactive Material (NORM) Coordinated Research Project (CRP). Specifically, the U.S. examined the technical approaches used in the derivation of exempt activity concentration values and compared doses attributed to the transport of materials that are either included or not included in the provisions of Paragraph 107(e) of *TS-R-1*. Also, the U.S. evaluated the different treatment of progeny in the A_1/A_2 values, which are derived using the Q-system, to the progeny identified for the exemption values. The conclusions based on these examined areas are given below.

Evaluation of the basis or derivation 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) was examined. Regarding the 10x provision, 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 and close to the "prudent" dose constraint of 0.1 mSv.

Regarding the PIU provision of Paragraph 107(e), it was concluded that:

- The PIU 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 PIUs of the material being transported.

Comparison of doses attributed to the transport of materials that are either included or not included in the provisions of Paragraph 107(e) of *TS-R-1* resulted in the following observations:

- The NPIU mineral ores and products dominated the 1 to 10 Bq g^{-1} range. However, there were some alternate feed materials (PIU) that had activity concentrations within the 1 and 10 Bq g^{-1} range. The greater than 10 Bq g^{-1} category primarily contained ores and products intended for use of radionuclides (PIU).
- Derived activity concentrations that resulted in an annual dose of 10 μSv (based on normalized doses) ranged between 0.2 and 14 Bq g^{-1} regardless of PIU.
- Normalized doses that resulted from an activity concentration of 10 Bq g^{-1} ranged from 0.01 to 0.4 mSv, with an average annual dose of about 0.1 mSv regardless of PIU. These doses are considerably lower than the IAEA "practical dose constraint" of 1 mSv and within the range of the "prudent" dose constraint of 0.1 mSv.
- There are ores and ore concentrates, such as copper and vanadium, which are co-mined or produced as a by-product of uranium ore processing. These ores and alternate feed materials are most impacted by the PIU exemption. In this case, all transport segments are potentially regulated (before and after uranium extraction).

Based on the evaluation of doses due to transport of low-level NORM, it is suggested that the transport regulations should be revised so that all natural materials (regardless of PIU and provided that the ten times limit of Paragraph 107(e) is met) are subject to the same exemption provisions. This approach requires a supporting revision to the material specification applicable to LSA-I materials in *TS-R-1* Paragraph 409(a)(i). This supporting revision would clarify that all uranium and thorium ores

and concentrates, and other ores containing NORM, regardless of their PIU, are included in the LSA-I category if they exceed the ten times provision of Paragraph 107(e).

Several observations were made regarding footnotes (a) and (b) of Table 2 in *TS-R-1*. There were a number of cases when progeny were ignored in footnote (b) due to low yields. In addition, there were cases where the branching fractions for selected progeny in the footnotes differed from branching fractions defined in ICRP *Publication 107*. It was determined that the footnotes should be revised as follows:

- If a nuclide is listed in footnote (b), then it need not be listed in footnote (a).
- All nuclides in footnote (b) should be removed from footnote (a) and their references in the table changed from (a) to (b). This would indicate that the same physical information was used in deriving the limits.
- Presumably, future development of guidelines and dose estimates by the agency will be based on ICRP *Publication 107*.

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APPENDIXES

Appendix A. CANADIAN URANIUM RESOURCES

Mine	Operator	Tons U	Tons U_3O_8	Average ore grade	Category
Rabbit Lake	Cameco	6,745	7,950	0.98%	Proven and probable reserves
McClean Lake	Areva	2,500	2,950	0.67%	Proven reserves
		5,900	6,960	1.90%	Measured and indicated resources
McArthur River	Cameco	65,000	77,300	17.18%	Proven reserves
		62,640	73,860	26.33%	Probable reserves
		19,160	22,600	9.08%	Measured and indicated resources
		53,570	63,180	9.81%	Inferred resources
Cigar Lake	Cameco	87,000	102,860	20.67%	Proven reserves
		2,500	3,000	4.86%	Indicated resources
		45,500	53,700	16.92%	Inferred resources
Midwest	Areva	16,340	18,900	1.48%	Measured and indicated resources
Dawn Lake	Cameco	5,000	5,900	1.69%	Indicated resources
Millennium	Cameco	18,060	21,300	4.53%	Indicated resources
		3,700	4,400	2.06%	Inferred resources
Kiggavik	Areva	15,550	18,340	0.27%	Inferred resources
Michelin	Aurora	26,000	30,600	0.11%	Measured and indicated resources
		13,670	16,100	0.12%	Inferred resources
Jacques Lake	Aurora	4,000	4,700	0.08%	Measured and indicated resources

Source: World Nuclear Association Uranium Production in Canada (updated September 15, 2009). http://www.world-nuclear.org/info/default.aspx?id=318&terms=uranium+ore+grade+Canada

Appendix B. ALTERNATE FEED MATERIALS LICENSED TO DATE FOR PROCESSING AT WHITE MESA MILL

Alternate feed[a]	Description[a]	Volume[a]	Average uranium content (wt % U)[a]	Activity concentration (Bq/g)
Linde	Soils contaminated with U	100,000 tons	0.07%	17.5
Ashland	Soils contaminated with U	172,600 tons	0.06%	15
Ashland	Soils contaminated with U	43,980 tons	0.009%	2.3
St. Louis	Soils contaminated with U	1,029,000 tons	0.09%	22.5
Maywood	Soils contaminated with ^{232}Th, U	250,000 tons	0.01%	2.5
Nevada Test Site Cotter Concentrate	Drummed slurry	363 tons	10.0%	2,500
Honeywell	Calcium fluoride waste stream. Licensed source material	5,443 tons	2.0%	500
Cabot	Ore residues from tantalum production. Licensed source material	16,830 tons	0.343%	85.8
Allied Signal	Aqueous potassium hydroxide (KOH) slurry and solids. Licensed source material	1,595 tons	17.0%	4,250
Rhone-Poulenc	Uranyl nitrate hexahydrate liquid concentrate	17 tons	50.0%	1.25E4
Cameco	Potassium fluoride product	1,966 tons	4.6%	1,150
Cameco	Uranium tetrafluoride with filter ash. Powdered solid	10 tons	65%	1.63E4
Cameco	Calcined raffinate	2,197 tons	5.5%	1,375
Cameco	Mono- and dibutyl phosphate. Regeneration product	557 tons	8.0%	2,000
W. R. Grace	Monazite sands and soil	203,000 tons	0.074%	18.5
Heritage	Monazite sands	2,910 tons	0.05%	12.5
Molycorp	Lead sulfide pond solids. Licensable source material	11,500 tons	0.15%	37.5
FMRI	Ore residues from tantalum production. Licensed source material	32,000 tons	0.15%	37.5

[a]White Mesa Uranium Mill, License Renewal Application, State of Utah Radioactive Materials License No. UT1900479, Denison Mines (USA) Corp. Denver, Co., February 28, 2007