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Regulatory Control for the Safe Transport of Naturally Occurring Radioactive Material (NORM)

Report of a Coordinated Research Project 2007–2010

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REGULATORY CONTROL FOR THE SAFE TRANSPORT OF NATURALLY OCCURRING RADIOACTIVE MATERIAL (NORM)

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REPORT OF A COORDINATED RESEARCH PROJECT 2007–2010

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

The use of radioactive material necessitates its transport in the public domain. During the transport of radioactive material, the protection of workers, the public and the environment must be ensured. Radiation hazards need to be evaluated and decisions regarding the degree of control that needs to be exercised to ensure safe transport need to be made.

The IAEA system for the exemption of radioactive material from the requirements of IAEA Safety Standards Series No. TS-R-1, Regulations for the Safe Transport of Radioactive Material (‘Transport Regulations’), is based on the principle that exemption values should be commensurate with the risk posed by the material. IAEA Safety Series No. 6 Regulations for the Safe Transport of Radioactive Material, 1985 Edition (updated 1990), defined radioactive material as any material having a specific activity greater than 70 Bq/g. This definition was irrespective of the radionuclides present within the material and provided a convenient guideline for the exemption of radioactive material from regulatory control.

The 1996 edition of the Transport Regulations introduced radionuclide specific exemption levels in lieu of the single 70 Bq/g value. Since then, ores, tailings and backfill from large mining operations (e.g. phosphate, coal, gold and mineral sands) were brought within the scope of the Transport Regulations. With this change to the exemption levels in the Transport Regulations, materials that were not previously considered radioactive material for transport purposes now became subject to packaging, communication, training and emergency response requirements. This situation significantly increased the cost of shipping certain materials.

The July 2003 International Conference on the Safety of Transport of Radioactive Material identified a need for additional research to relieve the unnecessary regulatory burden associated with the transport of very low activity naturally occurring radioactive material (NORM). In response to this need, the IAEA undertook a coordinated research project to identify the types of NORM materials transported and the resulting radiation doses to workers and the public as a result of transport.

Nine Member States participated in the coordinated research project: Brazil, Canada, France, Germany, the Islamic Republic of Iran, Israel, Romania, the United Kingdom and the United States of America. A wide range of materials from NORM industries were reviewed, including those used for extraction of minerals (e.g. tantalum ores, zirconium ores, concentrates of such ores, etc.), direct use materials (e.g. phosphate and potash), scales from oil and gas extraction industries, ores and waste material from uranium processing and other materials. Participating countries conducted surveys of industries involved in the transport of NORM and assessed doses to workers and members of the public through modelling and by direct measurement. Several participants also carried out assessments of doses associated with the transport of NORM based on a normalized modelling approach for unit activity concentrations in the material transported for a number of radionuclides (^{40}K, ^{238}U, ^{235}U, ^{226}Ra, ^{228}Ra, U(nat) and Th(nat)).

The results of the studies and several conclusions about regulatory provisions that should be more closely aligned with expected doses during transport were agreed upon by all participants, and are presented in this publication. Individual country reports are available for review in the accompanying CD-ROM. In addition, the recommendations of this coordinated research project have been reflected in the 2012 edition of the Transport Regulations and associated Safety Guides.

Radionuclide specific exemption levels and an allowance of a ‘factor of 10’ higher than the exemption levels for NORM, provided they were not intended to be processed, were introducd in the 1996 Transport Regulations. This coordinated research project was undertaken in accordance with a recommendation from the International Conference on the Safety of Transport of Radioactive Material (2003), which suggested that the full impact of and technical basis for the ‘factor of 10’ exemption be thoroughly researched. Additionally, the results provide guidance to Member States on how best to regulate NORM.

T. Ciabanca, U. Schwela and P. Scofield are to be thanked for their significant contributions to the finalization of this publication. The IAEA officer responsible for this publication was K.K. Varley of the Division of Radiation, Transport and Waste Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The Transport Regulations apply to radioactive material, regardless of whether it contains radionuclides of natural or artificial origin. Naturally occurring radioactive material (NORM) is radioactive material containing no significant amounts of radionuclides other than naturally occurring radionuclides. Radionuclides of natural origin are present naturally on Earth in significant quantities. The term is usually used to refer to the primordial radionuclides potassium- 40, uranium-235, uranium-238, thorium-232 and their radioactive decay products. Natural uranium contains the naturally occurring distribution of uranium isotopes which is approximately 99.28% uranium-238 and 0.72% uranium-235 by mass. In all cases, a very small mass percentage of uranium-234 is present.

The IAEA Regulations for the Safe Transport of Radioactive Material, 1985 Edition (As Amended 1990) Safety Series No. 6 [1] defined radioactive material as any material having a specific activity greater than 70 Bq/g. This provided a convenient guideline for exemption of radioactive material from regulatory control. 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 dose criteria where the annual effective dose should in the order of 10 μSv (1 mrem) or less [2]

During the development of the 1996 Edition of the Transport Regulations [3], a new definition of radioactive material was adopted that was consistent with the exemption values of the IAEA's GSR Part 3 [2]. The exemption values were derived by using a variety of exposure scenarios and pathways that did not explicitly address the transport of radioactive material. Additional calculations were undertaken for transport specific scenarios [4]. These transport specific exemption values were then compared with the values in the GS-R Part 3 [2]. It was concluded that the relatively small differences between both sets did not justify the incorporation into the Transport Regulations of a set of exemption values different from that in GS-R Part 3. Exemption in terms of activity concentrations and total activity derived for inclusion in the IAEA's GSR Part 3 is now applied to the transport of radioactive material. Exemption values were derived for three naturally occurring chains of radionuclides, the ^{226}Ra, ^{232}Th, and ^{238}U chains. In each case, the radioactive progeny are assumed to be in secular equilibrium with the nuclide heading the chain.

The exemption limits listed in the Transport Regulations are 1 Bq/g for both Th (nat) and U (nat). Recognizing that the exempt activity concentration values would bring large quantities of natural materials used in industry and not normally regulated as "radioactive" into the scope of the Transport Regulations. The exemption limits were raised by a factor of 10 for natural materials and ores "whose usefulness does not lie in the fissile, fertile or radioactive properties of those nuclides", including materials processed by physical and/or chemical means provided the purpose was not to extract radionuclides. Specifically, natural materials that are not intended to be processed for the recovery of their radionuclides and which do not exceed 10 times the exempt activity concentration were excluded from the scope of the Transport Regulations [3]

The value of 10 Bq/g for ^{238}U or ^{232}Th for naturally occurring decay chains that normally occur in minerals and ores not intended to be processed for the use of these radionuclides was introduced.

In July 2003 an International Conference on the Safety of Transport of Radioactive Material took place in Vienna, Austria, to address a range of important issues associated with the safe transport of radioactive material. Since the 1996 edition of the IAEA's Regulations for the Safe Transport of Radioactive Material introduced radionuclide-specific exemption levels in lieu of the single 70 Bq/g value in Safety Series No. 6 [1], ores, tailings and backfill from large mining operations (e.g. phosphate, coal, gold and monazite) were brought within the scope of the Regulations. To address this situation, the 1996 Regulations included an allowance for a "factor of 10" higher than the exemption quantities for naturally occurring materials, provided they were not intended to be processed to extract the naturally occurring radionuclides [3].

At the Conference, amongst the issues identified for further work was reconsideration of the applicability of transport regulations to naturally occurring radioactive material (NORM). The Conference identified a need for additional research to relieve unnecessary regulatory burdens related to the transport of very-low-activity NORM. The Conference noted the potential inconsistency between this provision and the development of international guidance on the more general issue of the scope of regulatory control in [5]**,** the problems associated with determining the ultimate use of the material and the inconsistency of excepting doses associated with some types of sources (e.g. NORM) but not doses of the same magnitude from other source types. The Conference suggested that the full impact of and technical basis for the "factor of 10" exemption be thoroughly researched.

Subsequent to the conference, the Board of Governors approved the Action Plan for the Safe Transport of Radioactive Material, Action (xiv). The action plan urges "The Secretariat, to initiate, in response to Member States' commitment, a Coordinated Research Project (CRP) on the appropriate level of regulatory control for the safe transport of naturally occurring radioactive material (e.g. ores and other materials)." The Transport Safety Standards Committee (TRANSSC) recommended initiating this CRP in March 2004.

2. SCOPE AND OBJECTIVES OF THE PROJECT

2.1. SCOPE

Some materials, in addition to uranium or thorium ores, contain relatively high levels of radionuclides of natural origin. However, the uses of these ores and materials necessitate their transport in the public domain. With the change to the exemption levels in the IAEA's Transport Regulations, 1996 Edition [3] materials which previously were not considered radioactive material for transport purposes are now subject to the packaging, communication, training and emergency response requirements. This situation significantly increased the cost of shipping certain materials. Consequently, radiation hazards needed to be evaluated and decisions made regarding the degree of control that should be exercised to ensure their safe transport. During the transport of these materials, the radiological safety of the worker, the public and the environment must be ensured.

As the Member States were concerned over the changes that were implemented in the 1996 edition of the Transport Regulations, the IAEA felt that a sound basis was needed for the current requirements or for introducing appropriate amendments to the requirements. Topics were identified that could lead to recommendations to revise the Transport Regulations (e.g. the factor of 10 and the 'intended use' limitation in paragraph 107[e]). The data collected by this CRP will be used to determine the effectiveness of the Transport Regulations and recommend revisions to the Transport Regulations, if appropriate, to accommodate the new information.

Therefore, the scope of the CRP was aimed at the collection, review, analysis and evaluation of internationally existing material and information on transport and packaging of NORM.

2.2. OBJECTIVES

This CRP was intended to address vital transport safety issues and to allow full use to be made of currently existing material, methods and experience and firm conclusions. The research topics were to address all aspects of the transport of NORM.

The general objective was to evaluate the effect and hazard of low-level radioactive materials and analyse the conditions under which these radioactive materials are transported. Additionally, the appropriateness of the existing regulations to the hazard of the transported materials was to be investigated.

Participating countries had to consider transport environments, under both normal and accident conditions, with the potential to result in dispersal of radioactive material. To meet these objectives, the participants in the CRP were requested to include the following in their studies and analyses:

- Typical loading of packages containing NORM;
- Types of packaging that are used for transporting NORM;
- Performance of packaging under normal and accident conditions of transport and the extent of dispersal of contents;
- Consequences of transporting certain specific NORM unpackaged;
- Risk impacts due to breach of containment or confinement for the radioactive materials.

2.3. RELEVANCE OF PROJECT OBJECTIVES TO TRANSPORT REGULATIONS

The data collected for this CRP has been used to determine the effectiveness of the Transport Regulations and recommend revisions to the Transport Regulations. Recommendations from a CRP do not feed directly into the process for revision of the IAEA Transport Regulations. One or more Member States interested in pursuing recommendations from a CRP should submit proposals for change to the IAEA. Proposals for changes to the regulations should be submitted complete with proposed text for the revised regulations and the related advisory material and with justification for the proposed changes. The results of the CRP may be used to revise the Regulations or to develop guidance material in TS-G-1.1[6] to address transport and packaging of NORM.

2.4. REGULATORY CONTEXT

The transport of radioactive materials is regulated internationally by the IAEA. The IAEA Transport Regulations are considered to represent the general international consensus on transport issues, which officially become regulations only when they are adopted into national and international laws by countries and international agencies.

The transport of NORM is an international concern. The IAEA issued its first safety series on international and national transport of radioactive material by all modes in 1961. Reviews conducted with Member States and international organizations concerned with transport resulted in several revisions, the most recent in 2012 [7]. After the first revision (1964), the regulations were applied to all IAEA and IAEA-assisted operations; and by 1969, almost all of the international organizations concerned with transport, as well as Member States, had adopted the regulations. The IAEA has also published two companion standards that provided the advisory [8] and explanatory material [9] relating to the regulations; however, in support of the 1996 edition of the regulations (known as TS-R-1), the IAEA published a companion volume that included both advisory and explanatory material [10].

The 1996 TS-R-1 transport regulations [3] provide radionuclide-specific activity concentration (Bq/g) and radionuclide-specific total activity (Bq) exemption values below which the regulations do not apply. Both the concentration and total activity limits must be exceeded in the consignment before the transport regulations apply.

These exemption values were initially derived for inclusion in GSR Part 3 [2], which in turn was taken from the European Commission report RP-65 [11]. They were derived using a set of representative exposure scenarios that would give rise to doses for appropriate critical groups that corresponded to the dose criteria for the exemption practices. The main dose criterion for exemption set out in the IAEA's GSR Part 3 is that "the effective dose expected to be incurred by any member of the public due to exempted practice or source is of the order of 10μSv or less in a year" [2]. Schedule I of the BSS provides exemption levels (activity concentrations and total activities) that can be used to exempt practices without any further consideration. The individual dose criterion of 10 μSv/y dose was considered to represent an insignificant, trivial level of risk. The IAEA refers to this dose rate as being "… sufficiently low as to be of no regulatory concern" [2].

Another criterion for derivation of the exemption values was that the collective dose associated with the values (i.e. the summed dose to all impacted individuals) would not exceed 1 man-Sv [2]. However, it has since been generally concluded that the individual dose would almost always be the limiting factor.

The dose criteria adopted in the derivation of exemption values in the RP-65[11] report were based on the concept of exemption and its underlying principles elaborated by the IAEA in RS-G-1.7) [5]. RS-G-1.7 concluded that an individual dose of a few tens of microsieverts provided a basis for exemption, and that if exposures of individuals from more than one exempt practice are taken into account, the doses to the critical group from each exempt practice should be of the order of 10µSv/y. IAEA also required the collective dose to be as low as reasonably achievable (ALARA) and suggested that it may be assumed to be so if it is below 1man Sv/y of practice [2].

Safety Report Series 44 [12] notes that the objective in defining material that contains radionuclides of natural origin that should be excluded from the requirements of GSR Part 3[2] is to identify that material of significant radiological risk for which regulation will not achieve real improvements in protection. The report also suggests that the application of a dose criterion of 10 µSv/y is not practical and rather, suggests that the exemption values should be derived from consideration of the worldwide distribution of concentrations of radionuclides of natural origin. This was done in paragraph 3.3 of the IAEA Safety Guide RS-G-1.7 [5], leading to the values of 10 Bq/g for ^{40}K and 1Bq/g for all other radionuclides of natural origin. Paragraph 5.11 of that publication further explains that “A graded approach consistent with the optimization principle can be taken when activity concentrations exceed the values given in Tables 1 and 2 of this Safety Guide.” Such an approach “shall be commensurate with the characteristics of the practice or source and with the magnitude and likelihood of the exposures and shall also conform to any requirements specified by the [regulatory body] or, whenever applicable, by the relevant Sponsoring Organizations [of GSR Part 3]” (Ref. [1], paragraph 2.8). Paragraph 5.12 states, “For activity concentrations that exceed the relevant values in Table 1 or Table 2 by several times (e.g. up to 10 times), the regulatory body may decide (where the national regulatory framework so allows) that the optimum regulatory option is not to apply regulatory requirements to the legal person responsible for the material.”

In its paragraph 401.4, IAEA TS-G-1.1 [6] also notes that the scenarios used to derive the exemption values in the GSR Part 3 [2] were not specifically related to transport situations. Subsequent calculations for transport scenarios were performed for a small group of representative radionuclides [4] and showed that almost all the exemption values thus derived were to be within an order of magnitude of the values in RP-65 [11]. Hence to avoid potential complications, the exemption values derived for the GSR Part 3 were adopted for the transport regulations.

Exemption values applicable to the transport of NORM are defined in paragraph 107(e) of IAEA TS-R-1 [13]: “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 paragraphs 403-407.”

Further explanation of the exemption values for NORM defined in paragraph 107(e) is provided in TS-G-1.1 [6], paragraph 107.4: “factor of 10 times the exemption values for activity concentration was chosen as providing an appropriate balance between the radiological protection concerns and the practical inconvenience of regulating large quantities of material with low activity concentrations of naturally occurring radionuclides.”

In discussing the need for radiation protection in NORM industries, IAEA Safety Report No. 49 [14] notes that for situations where occupational exposure to gamma radiation and radionuclides in dust are the principal exposures of concern, as is likely to be the case in most NORM industries, it is recommended that regulatory agencies choose activity concentrations of parent nuclides within the range of 1–10 Bq/g to determine whether the exposures from these materials should be regarded as “occupational,” while noting that, on the basis of pessimistic assumptions, activity concentrations in this range “will lead to an effective dose of about 1–2 mSv in a year.”

3. CRP APPROACH

The IAEA established a CRP on the Appropriate Level of Regulatory Control for the Safe Transport of Naturally Occurring Radioactive Material (NORM). An initial preparatory meeting was held November 2006. Thereafter, three RCMs were held at IAEA, Vienna, Austria, in April 2007, February 2008 and November 2009.

Experts from nine countries participated in the CRP: Brazil, Canada, France, Germany, the Islamic Republic of Iran, Israel, Romania, the United Kingdom and the United States of America. Australia produced a report, which was made available to the participants of the CRP, but did not take part.

A wide range of materials from NORM industries were reviewed in the studies, including tantalite and tin slag, phosphate, potash, zirconium (zircon sands) and other materials for the ceramics industries, scales from oil and gas extraction industries, coal and coal ash, residues from waterworks, wastes from rare earths extraction, ore and waste material from uranium mines. For each of these materials, experts characterized the radionuclides, their activity concentrations, the volumes transported as the typical loading of packages containing NORM and the types of packages used to transport NORM.

Some of the participating countries conducted surveys of national industries involving transport of NORM and an assessment of doses to workers and members of the public associated with the transport of NORM. These doses were evaluated using a combination of models and measurements and were based on work practices in place in these countries. Doses were generally calculated for drivers (either employees or members of the public) transporting material in a conveyance (road, rail and sea) and for individuals (either employees or members of the public) loading materials into a conveyance. Information such as time spent driving or loading, distances from the material and so on was used to characterize transport operations and develop exposure scenarios.

Canada, France, Germany and Israel also carried out an assessment of doses associated with the transport of NORMs based on a normalized modelled approach for unit activity concentrations in the material transported for a number of radionuclides (^{40}K, ^{238}U, ^{235}U, ^{226}Ra, ^{228}Ra, U-nat and Th-nat).

The individual research agreements included under this CRP were:

- Brazil: Exempt and Low Specific Activity (LSA) Quantities for the Transport of NORM Radioactive Material;
- Canada: Radiological Assessment of the Transport of Tantalum Raw Materials;
- France: The Adequacy of the Regulations for the Transport of Naturally Occurring Radioactive Material;

- Germany: Exposure of Transport Workers from the Transport of Most Important NORM in Germany;
- Islamic Republic of Iran: Radiological Risk Assessment of the Transport of NORM;
- Israel: Assessment of Occupational Exposure during Activities Related to Transport of Phosphate and Potash;
- Romania: Risk and Safety Evaluation in the Transportation and Disposal of Naturally Occurring Materials—Uranium Ore and Uranium Waste in Romania;
- United Kingdom: A Study on the Transport of Naturally Occurring Radioactive Material and
- United States of America: Evaluation of Activity Concentration Values and Doses Due to the Transport of Low Level Radioactive Material.

3.1. PARTICIPANT COUNTRY PRINCIPAL OBJECTIVES

This section summarizes the participant country technical objectives.

Brazil

The main objectives of the Brazilian study were to establish the quantities of NORM that can be exempted from IAEA Transport Regulations, to specify the quantities of NORM that can be transported in excepted packages and to provide a sound basis for the classification of NORM as low specific activity (LSA–I).

Canada

The main objectives of the Canadian study were the chemical and physical analysis and radiation survey of NORM material (tantalite and tin slag). A model showing the relationship between tantalum raw materials and expected dose rate was developed. The radiation doses to transport workers and the public were evaluated and a report prepared for submission to the CRP with proposed Th-nat and U-nat radionuclide exemption levels appropriate for these materials.

France

The overall objective of the French contribution was to make an overview of the NORM transported in France and carry out a dosimetric study of workplaces linked to the transport of NORM. An additional objective was to propose A_2 values in place of the unlimited values currently presented in Table 2 of TS-R-1(2009 Ed.) [13] for ^{235}U, ^{238}U, ^{232}Th, uranium and thorium in natural state.

Germany

The overall objective of the German contribution was to review and categorize the most important materials containing natural radionuclides in Germany. This included the review, analysis and evaluation of radiation exposure imposed by the shipment of NORM and expected exposure of the shipment staff and the population. In addition, Germany developed evaluation criteria and safety requirements to provide adequate safety standards for the transportation of NORM and developed procedures to determine the limits for exempt materials/consignments for transportation according to Transport Regulations for all NORM.

Islamic Republic of Iran

The objectives of the Islamic Republic of Iran study were to examine bulk shipments of phosphate rock from Morocco and Jordan, measure dose rates from material, and determine exposures to a variety of workers involved during vessel discharge and unloading and during cleaning and transport operations. The study also included an assessment of the annual external gamma exposure for a road truck driver. Loading of a truck with large bags was carried out by means of forklift truck in a storage area; the material was then transported by road to different facilities at different distances (500 km to 1500 km) throughout the country.

Israel

The main objective of the Israeli study was to estimate occupational exposures related to the transport of potash, phosphate rock and phosphate fertilizers. Those materials are transported on a bulk scale (a few million tons per year) in an unpackaged form.

Romania

The main objective of the Romanian study was to identify and evaluate the potential risks and safety aspects related to the transport and disposal of uranium ore and waste from uranium mines for both road and rail. In addition, the study examines tailing sites and related values of radon doses to the population and includes a survey of the major uranium production facilities and an estimation of accident frequencies for transport of uranium ore by road and rail.

United Kingdom (UK)

The objective of the UK study was to survey NORM transport operations and assess the radiological implications of those operations.

United States of America (USA)

The objective of the US study was to review doses arising from the transport of uranium-bearing materials to determine whether the restriction in paragraph 107(e) for materials “not intended to be processed for use of these radionuclides” was justified on a technically defensible basis [3].

3.2. CROSSWALK OF PROJECT OBJECTIVES AND TECHNICAL TOPICS FOR EACH COUNTRY

Table 1 illustrates the different areas of work, while the Tables 2-7 detail some of the objectives, parameters, scenarios and preliminary results. Table 4 summarises some real scenarios that participants covered, while Tables 5 and 6 cover the standard scenarios which will be used for calculation comparison only.

Tables 1 and 2 summarize the technical objectives and activities conducted by the participant countries (e.g. which country conducted measurements and/or modelled doses).

TABLE 1. PROJECT OBJECTIVES

Technical topic	Brazil	Canada	France	Germany	Islamic Republic of Iran	Israel	Romania	United Kingdom	United States of America
Calculate the limiting upper values for classification of NORM as LSA-I	X								
Calculate the quantities of NORM in excepted packages, based on A_1 and A_2	X			X	X				
Calculate the A_2 of NORM by Q system	X		X						
Provide sound theoretical basis for limits adopted by IAEA regarding LSA-I	X								
Propose new values to the IAEA for exclusion of NORM materials	X	X		X		X			
Develop model for relationship between activity and dose rate	X	X		X				X (if possible)	
Evaluate doses to transport workers and the public	X	X	X	X	X	X	X	X	X
Evaluate exposure from accident scenario	X	X					X		

TABLE 1. PROJECT OBJECTIVES (cont.)

Technical topic	Brazil	Canada	France	Germany	Islamic Republic of Iran	Israel	Romania	United Kingdom	United States of America
Consider validity of exemption and exclusion levels	X	X	X	X	X	X			X
Evaluate doses to workers during loading/unloading and storage during transit		X	X	X	X	X		X	
Consider general exemption for specific types of NORM	X	X				X			
Examine areas for radon doses				X	X	X	X		
Determine collective population doses					X		X		
Determine air dispersion factors				X			X		
Evaluation of background doses near sites					X		X		
Apply 107(e) to all NORM equally	X			X					X
Evaluate transport differences between non-fuel and fuel cycle NORM	X								X

TABLE 2. PROJECT TECHNICAL TOPICS [a]

Technical topic[b]	**Brazil**	**Canada**	**France**	**Germany**	**Islamic Republic of Iran**	**Israel**	**Romania**	**United Kingdom**	**United States of America**
Characterization of NORM (e.g. radionuclides, activity concentrations, shipment volumes)		X	X	X	X	X		X	X
Typical loading of packages containing NORM		X	X	X	X			X	X
Types of packages used to transport NORM		X	X	X	Bulk only	Bulk only	X	X	X
Dose rate measurement or calculations from packages and conveyances	X	X	X	X	X	X		X	
Transport operations characterisation (e.g. exposure scenarios, times, distances, intakes)		X	X	X	X	X		X	X
Measurement and modelling of worker doses		X	X	X	X	X	X	X	X
Modelling of public doses, including implications for non-occupationally exposed workers	X	X	X	X			X	X	

TABLE 2. PROJECT TECHNICAL TOPICS [a] (cont)

Technical topic	**Brazil**	**Canada**	**France**	**Germany**	**Islamic Republic of Iran**	**Israel**	**Romania**	**United Kingdom**	**United States of America**
Package performance under normal and accident conditions (extent of dispersal of contents)		X							
Consequences of transporting certain specific NORM unpackaged			X			X	X	X	X
Risk impacts due to breach of confinement of the radioactive materials (modelling accident risks)	X	X							
Analysis of regulatory provisions (e.g. 107(e), LSA-I definition, unirradiated uranium definition)	X	X	X	X	X	X		X	X

[a] The full descriptions of the studies are given in the project proposals.
[b] Topics in italics are drawn from the Logical Framework Outputs defined in the TRANSSC 10 IP14 document, Section 9 [15].

TABLE 3. PARAMETERS USED IN REAL SCENARIOS

Technical topic	Brazil	Canada	France	Germany	Islamic Republic of Iran	Israel	Romania	United Kingdom	United States of America
Truck driver: time transporting NORM, h/y	100	360	600[a]	20–500			240	600	18–2000
Truck driver: distance from load, m	1	3	2.5	1–2			1.5–2	1	Varied
Time loading/unloading/other workers, h/y		72	400[a] -1785			500			
Truck load size, m or tonne	Infinite source	6.1 ×2.4 ×1 and 6.1 × 1.2 ×1	4 × Ø1.5(truck) 15×Ø10(silo)	20–120 tons			13 tons	1.5×2×4	
Shielding: truck, cm	0	0.3–0.5	1	0.5–2.0			0.5	1.0	
^{40}K activity concentration, Bq/g			0.45-1.7			16			
Th-nat activity concentration, Bq/g	1	0.18–28	0.12-0.27[d]	0.1–15				0.6 (Zr)	0.4–10
U-nat activity concentration, Bq/g	1	2.4–92	0.084-0.246[d]	0.1–75	1.5 (P_2O_5)-50 (U ores)	1.0–2.0	1	3.0 (Zr)	0.3–190
Mean Th+U activity concentrations found: Bq/g		17.7–25.3						As above	1–200

TABLE 3. PARAMETERS USED IN REAL SCENARIOS (cont.)

Technical topic	Brazil	Canada	France	Germany	Islamic Republic of Iran	Israel	Romania	United Kingdom	United States of America
Ra-226+Ra-228 activity concentration Bq/g			0.37-0.49 [d]	0.2–1000				40	
Density	1.5	2–3	0.8-1.2	2–5					
Particle size (AMAD),[c] μm		5		2–10	5	4–13			
Dust loading, mg/m^3	65	0.1	10	0.5		2–6			
Breathing rate, mg/h			1.2-1.69 [d]						

[a] Driver and loader is the same person in this scenario.
[b] Combined radium in equilibrium with decay products.
[c] Activity median aerodynamic diameter
[d] Activity of the head of decay chain (U-nat, Th-nat) or chain segment (Ra).

Table 3 summarizes the time spent loading and unloading, truck driving distances and times, truck parameters, NORM activity concentrations and other parameters associated with the participant country studies. The time spent transporting and loading and unloading NORM varied widely among the various studies. The distances of the truck driver from the load were similar, ranging from 1-3 m. The activity concentrations varied according to the type of NORM evaluated by each participant. Dust loading varied considerably, ranging from 0.1-65 mg/m^3 loadings.

4. RESULTS

4.1. DOSE ASSESSMENT RESULTS

Table 4 summarizes the dose rates and annual doses based on participant study results. The nine projects examined a wide variety of materials, whose range of yearly doses was noted to be in line with existing radiation protection documents.

At the second RCM, it was proposed that each country calculate the dose rate per unit of activity concentration according to a set of standard scenario parameters agreed upon at the meeting. This proposal was intended to facilitate comparison of calculation methods. France carried out calculations for the external and internal doses, whereas Canada calculated the external dose only. France also calculated the external dose for two additional scenarios

Table 5 summarizes the physical parameters and activity concentrations associated with the Canadian and French assessments of doses resulting from the transport of NORM based on a normalized modelled approach for unit activity concentrations in the material transported for ^{40}K, ^{226}Ra, ^{228}Ra, U-nat and Th-nat. Where Canada and France carried out the same calculations, there is excellent agreement between the two sets of results. As the material composition was not specified at the time of the second RCM, Canada used a typical composition for tantalum raw materials and France used concrete; both calculations were performed using MicroShield.

Throughout this report, any reference to the radionuclides ^{226}Ra, ^{228}Ra, Th-nat and U-nat refers to the parent nuclide only and assumes that the parent nuclide is in secular equilibrium with its progeny, as per TS-R-1 (2009) Table 2 footnote b [13].

TABLE 4. COLLECTIVE DOSE RESULTS

Technical topic	Brazil (ore)	Canada	France	Germany	Islamic Republic of Iran	Israel	Romania	United Kingdom	United States of America
Dose Rates and Yearly Doses									
Packaged—Driver									
External dose rate: μSv/h		0.024–0.033 (1 Bq/g)		0.006–0.08 (1 Bq/g)			0.3–20	0.007–1	
External dose: mSv/y		0.16–0.24		<0.01–0.1				0.08–0.18	0.01–0.37
Packaged—Loader									
External dose rate: μSv/h		0.23–0.35 (1 Bq/g)	0.135	0.02–0.15 (1 Bq/g)					
External dose: mSv/y		0.31–0.49	0.0548	<0.01–0.2					
Packaged—Public									
Routine dose: μSv/y		0.1–0.4						<0.01–0.1	
Unpackaged—Driver									
External dose rate: μSv/h	0.20 (1 Bq/g)		4.8×10^{-3} – 6.8×10^{-2}						

TABLE 4. COLLECTIVE DOSE RESULTS (cont.)

Technical topic	**Brazil (ore)**	**Canada**	**France**	**Germany**	**Islamic Republic of Iran**	**Israel**	**Romania**	**United Kingdom**	**United States of America**
External dose: mSv/y			0.03				0.25		
Internal dose: mSv/y			0.008						
Unpackaged—Loader									
External dose rate: µSv/h						0.15–0.3			
External dose: mSv/y						0.08–0.15			
Internal dose: mSv/y			0.288			0.08–0.15			
Unpackaged—Public									
Routine dose: µSv/y						<10			
Accident external dose: µSv	0.1 (1 Bq/g)								
Accident inhalation dose: µSv	5×10^{-5} (1 Bq/g)								

TABLE 5. COLLECTIVE RESULTS FOR NORMALIZED SCENARIOS

Technical topic	**External—driver**	**External—loader**	**External—forklift truck driver**	**Internal**
Worker distance from load, m	1.5	1.5 (a) 8 (b)	0.5	
Load size, m	7 ×2 × 1.5	7 × 2× 1.5 (a) 15 × Ø10 (b)	1 ×1 × 1	
Shielding, cm	0.5	0.5 (a) 1 (b)	0	
^{40}K activity concentration 1 Bq/g, dose rate μSv/h	Canada: 0.0059 France: 0.0058	0.018	0.012	
Th-nat activity concentration 1 Bq/g, dose rate μSv/h	Canada: 0.092 France: 0.092	0.29	0.2	
^{228}Ra activity concentration 1 Bq/g, dose rate μSv/h	0.092	0.29	0.2	
U-nat activity concentration 1 Bq/g, dose rate μSv/h	Canada: 0.063 France: 0.062	0.19	0.13	
^{226}Ra activity concentration 1 Bq/g, dose rate μSv/h	0.063	0.19	0.13	
Density	2.5	2.5	2.5	2.5

TABLE 5. COLLECTIVE RESULTS FOR NORMALIZED SCENARIOS (cont.)

Technical topic	**External—driver**	**External—loader**	**External—forklift truck driver**	**Internal**
Particle size, µm				5
Dust loading, mg/m^3				1
Breathing rate, m^3/h				1.2
Th-nat activity concentration 1 Bq/g, inhalation dose rate µSv/h				5.8×10^{-2}
^{228}Ra activity concentration 1 Bq/g, inhalation dose rate µSv/h				4.3×10^{-2}
U-nat activity concentration 1 Bq/g, inhalation dose rate µSv/h				4.8×10^{-2}
^{226}Ra activity concentration 1 Bq/g, inhalation dose rate µSv/h				4.9×10^{-3}
Ingestion rate, mg/h				1
Th-nat activity concentration 1 Bq/g, ingestion dose rate µSv/h				8.7×10^{-4}
^{228}Ra activity concentration 1 Bq/g, ingestion dose rate µSv/h				7.7×10^{-4}
U-nat activity concentration 1 Bq/g, ingestion dose rate µSv/h				1.3×10^{-3}
^{226}Ra activity concentration 1 Bq/g, ingestion dose rate µSv/h				1.2×10^{-3}

4.2. ANALYSIS OF REGULATORY PROVISIONS

On the basis of the dose assessment results, participants also carried out an analysis of regulatory provisions for the transport of NORM. The emphasis of this analysis varied from country to country and included consideration of the validity of exemption levels. Some countries proposed new values or revisions to the IAEA for exemption of NORM materials and consideration of the general exemption for specific types of NORM, and suggestions to modify regulations applying to transport of NORM (e.g. 107(e)) [13]. Table 1 identifies the participant country that evaluated the regulatory provisions. Summarized below are suggested regulatory revisions from Brazil, France, Germany and United States of America.

Brazil

Based on the assessments conducted by Brazil, it was shown that:

(A) A factor of 10 applied to the activity concentration for exempt material in Table 1 of the IAEA TS-R-1 Safety Requirements, 2009 Edition [13], although conservative, may be considered adequate to exempt NORM in secular equilibrium from the transport regulations.

(B) No limitation should be imposed on the classification of NORM in secular equilibrium as LSA-1 material.

(C) A factor of 20 can be applied to the Table 1 values to limit the activity concentration of NORM to be transported in excepted packages.

Therefore, the following modifications to the TS-R-1, 2009 Edition [13], can be suggested:

(1) Paragraph 107(e) should be modified to read as follows:

(107) These regulations do not apply to

(a) -----------
(b) -----------
(c) -----------
(d) -----------

(e) Natural material and ores containing naturally occurring radionuclides, provided the activity concentration of the material does not exceed 10 times the values specified in paragraphs 401–406

(2) Paragraph 409(a) (i) of the TS-R-1, 2009 Edition [13] should be modified to read as follows:

409. LSA material shall be in one of three groups:
(a) LSA-I
(i) Uranium and thorium ores and concentrates of such ores, and other ores containing naturally occurring radionuclides

(3) The title of Table 5 (TS-R-1, 2009 Edition) [13] should be modified and another line should be added to this table, as follows:

TABLE 6. ACTIVITY AND ACTIVITY CONCENTRATION LIMITS FOR EXCEPTED PACKAGES TS-R-1, 2009 [13]

Physical state of contents	**Instrument or article**	**Materials package limits**
Special form	—	—
Other forms	—	—
Liquids	—	—
Gases	—	—
—	—	—
—	—	—
LSA-I Materials	—	20 times the activity concentrations for exempt material

Canada

On the basis of the analyses of doses arising from the transport of tantalum raw materials described in the report, there is no apparent reason with regard to radiological dose for an exemption value as restrictive as the current value of 10 Bq/g for these materials (1 Bq/g for Th-nat or U-nat × 10 according to TS-R-1 paragraph 107(e)).

There is considerable allowance for truck drivers who transport tantalum raw materials also to transport other materials containing elevated levels of naturally occurring radioactivity without exceeding a cumulative annual dose of 1 mSv.

To account for the possibility of other transport-related exposures, an annual dose constraint of 0.3 mSv might be considered. Considering the conservatism in the dose calculations summarized in the report, an exemption value of 30 Bq/g (^{238}U + ^{232}Th) would result in doses that would be unlikely to exceed 0.3 mSv/y to the most exposed transport workers. Thus an exemption value of at least 30 Bq/g is considered safe and appropriate for the transport of tantalum raw materials.

Irrespective of the exemption value selected, the radiological dose assessments described in the report provide assurance to the tantalum industry and to its shippers that the doses arising from the transport of tantalum raw materials are low and well within international norms for both transport workers and members of the public.

France

The French position is to keep the current paragraph 107(e) as it is and to limit the factor of 10 on the activity concentration exclusion level to natural materials that are not intended to be processed for the use of their radionuclides.

Germany

On the basis of the dose calculation results for the transport of NORM, the following recommendations are given as far as the proposed dose limit of 0.3 mSv yr^{-1} for transport personnel is accepted.

(1) For bulky transport of NORM with radioactive equilibrium, the five-fold activity concentration for exempt material meets these requirements independent of the kind and use of such materials.

(2) Accordingly, paragraph 107(e) could be amended as follows:

- Delete the intended use (i.e., … other than for the extraction of the radionuclides, and that are not intended to be processed for use of these radionuclides …").
- Furthermore, the last part of the sentence in paragraph 107(e) related to paragraphs 403 to 407 should be replaced by a new paragraph which contains the limits for natural radionuclides only, i.e.:
    - 5 Bq/g for U–nat and Th-nat in case of radioactive equilibrium
- In case of radioactive non-equilibrium, the activity concentration for exempt material should be calculated by means of the formula in paragraph 405 of TS-R-1 with the following limitations:
    - 15 Bq/g for ^{226}Ra and 10 Bq/g for ^{228}Ra and
    - the 10-fold exempt limit of 100 Bq/g for ^{210}Pb and ^{210}Po, each in non-equilibrium, is thoroughly applicable regardless of the limitation to 50 Bq/g of each by application of the formula in paragraph 405 of TS-R-1.

United States of America

Based on the evaluation of measured and estimated doses associated with the transport of NORM for both prior and intended use of radionuclides (PIU) and not for prior and intended use (NPIU), the following regulatory revisions were recommended:

- 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 corollary clause from the definition of LSA-I. This definition includes "uranium and thorium ores and concentrates of such ores, and other ores containing naturally occurring radionuclides which are intended to be processed for the use of these radionuclides."

4.3. COUNTRY SUMMARIES

As mentioned earlier, the general objective of the CRP was to evaluate the effect and hazard of low-level radioactive materials and analyse the conditions under which these radioactive materials are transported. Additionally, the appropriateness of the existing regulations to the hazard of the transported materials was to be investigated. To meet these objectives, participating countries were asked to consider transport environments, under both normal and accident conditions, with the potential to result in dispersal of radioactive material. Summarized below are participant country study and analysis results.

4.3.1. Brazil: Exempt and LSA quantities for the transport of NORM

The main objectives of the present research work were (1) the provision of a sound basis to justify the established quantities of NORM that can be exempted from IAEA Transport Regulations, (2) the provision of a sound basis to classify all NORM in secular equilibrium as LSA–I material for transport purposes, and (3) the establishment of quantities of NORM that can be transported in excepted packages.

To this end, a mathematical model and a computer program were developed, using the MATHEMATICA software details of which are found in the report from Brazil on the [CD], taking into account the accident scenarios established in the Q system, slightly modified to adopt the very restrictive trivial dose of 10 μSv (10 μSv/h during 1/2 h) to the public in the case of an accident involving a NORM consignment. The Q-system considers a series of exposure routes for persons in the vicinity of a type a package involved in a severe transport accident.

A scenario with a dose constraint of 0.3 mSv/a to the driver for normal conditions of transport was also considered.

Based on the above assumptions, the following were shown that

(A) A factor of 10 applied to the activity concentration for exempt material in Table 1 of the IAEA TS-R-1 Safety Requirements, 2009 Edition [13], although conservative, may be considered adequate to exempt NORM in secular equilibrium from the transport regulations.
(B) No limitation should be imposed on the classification of NORM in secular equilibrium as LSA-1 material.
(C) A factor of 20 can be applied to the Table 1 values to limit the activity concentration of NORM to be transported in excepted packages.

Therefore, the following modifications to the TS-R-1, 2009 Edition [13], can be suggested:

(1) Paragraph 107(e) should be modified to read as follows:

(107) These regulations do not apply to

(a) -----------

(b) -----------

(c) -----------

(d) -----------

(e) Natural material and ores containing naturally occurring radionuclides, provided the activity concentration of the material does not exceed 10 times the values specified in paragraphs 401–406

(2) Paragraph 409(a) (i) of the TS-R-1, 2009 Edition [13], should be modified to read as follows:

409. LSA material shall be in one of three groups:

(a) LSA-I
(i) Uranium and thorium ores and concentrates of such ores, and other ores containing naturally occurring radionuclides

(3) The title of Table 5 (TS-R-1, 2009 Edition) [13] should be modified and another line should be added to this table, as follows:

TABLE 7. ACTIVITY AND ACTIVITY CONCENTRATION LIMITS FOR EXCEPTED PACKAGES TS-R-1, 2009 [13]

Physical state of contents	**Instrument or article**	**Materials package limits**
Special form	—	—
Other forms	—	—
Liquids	—	—
Gases	—	—
—	—	—
—	—	—
—	—	—
LSA-I materials	—	20 times the activity concentrations for exempt material

4.3.2. Canada

The Canadian submission is a study originally commissioned by the Tantalum–Niobium International Study Center (T.I.C.) into the transport of tantalum raw materials, specifically tantalite and tin slag. The main objectives were to determine the radiological characteristics of these materials and to evaluate the potential radiological exposures associated with normal transport and in the event of an accidental spill.

The T.I.C. is an international association with approximately 85 member companies around the world involved in mining, trading, refining/processing and end use of the metals niobium and/or tantalum. Tantalum is a nonradioactive element of which approximately 50% is used in electronics, to produce mainly capacitors but also filters and lenses. It provides an advantage by enabling the most compact capacitors and is thus found in devices such as Antilock

Braking System (ABS), airbag systems, car engine management, GPS, mobile phones, battery chargers, computers, hearing aids and pacemakers.

Approach to Study

Chemical and physical analysis and radiation surveys were carried out on 71 shipments of material in cooperation with TIC member companies, following protocols developed by Alfred H. Knight International, Ltd. (for representative sampling of tantalum raw materials and chemical and physical analysis) and SENES (radiation survey protocol).

Analysis of 67 of the shipments of tantalite and slag showed a range of about a factor of 10 in radioactivity concentrations, with an average activity concentration (^{238}U + ^{232}Th combined) of about 20 Bq/g for tantalite and about 25 Bq/g for slag. The majority (78%) of tantalite shipments and 45% of the slag shipments had concentrations exceeding 10 Bq/g.

A model showing the relationship between tantalum raw materials and expected dose rate was developed. Based on Microshield, it was found to provide a consistent but somewhat conservative estimate (overestimate) of measured gamma dose rates. This was primarily due to the assumption that the transport containers were always considered to be a full 1 tier or 1.5 tier load, whereas in practice the loading pattern was often less than full because of weight restrictions.

The radiation doses to transport workers and the public were evaluated and the completed report was submitted to the first RCM in April 2007.

Exposure Scenarios

The study considered both duration and location of exposure for several types of transport workers and for members of the public:

- Members of the public living along transport routes;
- Transport workers;
  - Truck driver;
  - Trainman;
  - Dockworker;
  - Seaman.

- Facility workers in shipping and receiving;
  - Workers associated with the loading and unloading of the sea–land containers were considered to be part of the on-site facility operations rather than transport workers.[1]

[1] Facility workers were deemed not to be transport workers in accordance with paragraph 107(b) of TS-R-1 (2009) [13], as the facilities sending and receiving tantalum raw materials were subject to appropriate safety regulations in force in those facilities, and the movement did not involve public roads or railways; even so the dose rates to facility workers were calculated to provide a comparison.

Main results

- Radioactive equilibrium in the uranium (^{238}U) and thorium (^{232}Th) decay series was found to be a reasonable assumption for tantalum raw materials for dose assessment purposes.
- Based on an evaluation of potential internal and external exposure pathways, external exposure to gamma radiation was determined to be the only significant exposure pathway.
- Doses from exposure to spilled materials due to potential accidents were calculated and determined not to be a regulatory concern, as the resulting doses were less than 10 μSv/y.
- Doses to members of the public from the transport of these materials were found to be insignificant, (much less than 10 μSv/y).
- The calculated doses to transport workers were well within the internationally accepted dose limit of 1 mSv/y for non-radiation workers.
- Truck drivers were found to be the most exposed transport workers. Assuming that the tantalum raw materials considered in this study reliably represent the likely range of tantalum raw materials in general, and then the expected (mean) dose to truck drivers would be about 0.24 mSv/y from slag and 0.16 mSv/y from tantalite.

Supplementary gamma dose-rate calculations were performed as the result of an action arising from the first RCM in April 2007. The specifications for the calculations are listed in Table 5 in the minutes of that meeting. The results of these reference gamma calculations for tantalum raw materials are described in a memorandum dated 25 February 2008, separate from the main report.

Conclusions

On the basis of the analyses of doses arising from the transport of tantalum raw materials described in the report, there is no apparent reason with regard to radiological dose for an exemption value as restrictive as the current value of 10 Bq/g for these materials (1 Bq/g for Th-nat or U-nat × 10 according to TS-R-1 paragraph 107(e)).

Even in the absence of any exemption value, Tables 4.5 and 4.7 in the report show no one would be expected to receive a dose above 1 mSv/y arising from the transport of tantalum raw materials.

There is considerable allowance for truck drivers who transport tantalum raw materials also to transport other materials containing elevated levels of naturally occurring radioactivity without exceeding a cumulative annual dose of 1 mSv.

To account for the possibility of other transport-related exposures, an annual dose constraint of 0.3 mSv might be considered. Considering the conservatism in the dose calculations summarized in Table 4.6 of the report, an exemption value of 30 Bq/g (^{238}U + ^{232}Th) would result in doses that would be unlikely to exceed 0.3 mSv/y to the most exposed transport workers. Thus an exemption value of at least 30 Bq/g is considered safe and appropriate for the transport of tantalum raw materials.

Irrespective of the exemption value selected, the radiological dose assessments described in the report provide assurance to the tantalum industry and to its shippers that the doses arising from the transport of tantalum raw materials are low and well within international norms for both transport workers and members of the public.

4.3.3. France

A French study was conducted on the basis of industrial workplace assessments. The French Institute for Radiological Protection and Nuclear Safety (IRSN) received 88 studies from different types of industrial facilities involved in NORM issues: coal combustion in thermal power plants; treatment of tin, aluminium, copper, titanium, niobium, bismuth and thorium ores; production of refractory ceramics, etc. Those studies represent 3,800 measurements performed on 475 samples of materials. France also studied the transport of uranium ore in France (from mines to concentrating plants) and of tails resulting from this activity.

Trying to draw an overview of all NORM transported in France, IRSN synthesized the results in the following four ways:

- Activity concentration in transported materials: France plotted the activity concentrations of each group of radionuclides (parent and short-lived daughters) for different types of NORM in these industrial facilities.
- Density of transported materials: France plotted the density of each transported material.
- Dust inhalation: France plotted the dust concentration at workplaces.
- Workplace: France plotted relevant parameters for persons in four usual occupations/ workplaces: truck driver, forklift driver, person in charge of loading and worker on a stack of radioactive material.

For each of these occupations/activities, France modelled occupational exposure on the basis of realistic parameters. Dose rates were evaluated for these four activities on the basis of an activity concentration of 1 Bq/g for each group of radionuclides and of different densities of material (ranging 1 -7). The conclusions of this evaluation are the following:

- The density of transported material has a low impact on dose rates. A density of 2.5 g/m^3 may be used for all materials.
- The external dose rates to the four occupations/activities are in the same order of magnitude.
- The evaluations are in good agreement with measurements.

With realistic scenarios of occupational exposure (truck driver and forklift driver), the evaluation indicated that

- Transport of 1 Bq/g of uranium ore induces an annual dose of about 100 -150 µSv.
- Transport of 10 Bq/g of radium wastes induces an annual dose of about 1- 1.5 mSv.

For NORM not intended to be processed for the use of its radionuclides, a factor of around 10 may be assumed to take into account the variability of the activities in the loadings transported all through the year. Taking into account that factor of 10, transport of an ore not intended to be processed for the use of its radionuclides, containing uranium up to 10 Bq/g, induces an annual dose of about 100 µSv.

Some materials, at equilibrium or not, can lead to an annual dose higher than 1 mSv. For example, an employee dealing with loading and transport of baddeleyite (raw material with a uranium activity concentration of 7 Bq/g) can reach an annual dose greater than 1 mSv/y in about 700 h only by external exposure. Moreover, an employee handling a big bag containing sands used for underground water filtration (^{226}Ra: 3.7 Bq/g; ^{228}Ra: 3.3 Bq/g) can receive an annual dose of 1 mSv in less than 1000 h only by external exposure. It is emphasized that this activity concentration in radium (7 Bq/g) is much lower than the exemption limit for a material not intended to be processed for the use of its radionuclides (100 Bq/g). Compared with the trivial dose of 10 µSv/y (used to determine exemption values), the values of the assessed doses seem to be high.

IRSN also estimated A_2 values for NORM using the Q system. Currently, the A_2 values for uranium and thorium are "unlimited," which appears inconsistent, on one hand, with the A_2 values of their immediate progeny and on the other hand with the method described in the Q system itself. IRSN thus recommends its assessed values be taken into account.

Eventually, during the third RCM, IRSN emphasized the need to keep paragraph 107(e) as it is currently written in the 2009 edition of the Transport Regulations [13].

Indeed, transports intended to feed the fuel cycle should present an annual average activity concentration higher than that for transportation not related to the fuel cycle: materials with the highest activity concentration are of interest for the fuel cycle, while loads with lower activity concentrations will tend to be rejected. Consequently, the annual dose to a driver working in the fuel cycle industry should be higher than the dose received by drivers working for other industries.

Moreover, drivers and loading workers involved in the transport of uranium ores intended to be used in the fuel cycle are handling and transporting NORM for a large amount of time. So the exposure time taken into account in the different studies of the CRP (800 - 900 h/ year), as well as the associated doses, is underestimated (cf. results presented earlier). If paragraph 107(e) of the TS-R-1 regulations is extended to those materials that will be processed for use of their radionuclides, the annual dose due to transport will reach 1.5 mSv/year (with a specific activity of 10 Bq/g). This annual dose is far above the reference annual dose of 10 µSv used in the definition of exemptions and even above the annual individual dose for a member of the public. Accordingly, an increase of the activity concentration exemption limit for materials intended to be processed for the use of radionuclides would not be consistent with other activity concentration exemption limits.

Furthermore, it should be noted that the additional constraints imposed for the transport of radioactive material are more easily achievable by companies working full-time for the fuel cycle industry, because these companies are aware of the radiation protection objectives. This is not the case for industries not linked to the fuel cycle.

Eventually, for security reasons, it is better to be able to follow the transport of any NORM intended to be processed for the extraction of its radionuclides, whatever its activity concentration.

In conclusion, the current exemption values are based on reasonable annual doses. The evaluation indicates that an increase in the exemption values would significantly increase the doses received by workers without any particular radiological monitoring. The French position is to keep the current paragraph 107(e) as it is and to limit the factor of 10 on the activity concentration exclusion level to natural materials that are not intended to be processed for the use of their radionuclides.

4.3.4. Germany: Exposure of transport workers during the transport of most frequently transported NORM in Germany

The German national report to this CRP was focused on the following services according to the research agreement:

(1) Status review, analysis and evaluation of the radiation exposure imposed by shipment and expected exposure of the shipment staff of the most relevant NORM in Germany;

(2) Development of evaluation criteria and safety requirements to provide adequate safety standards for the transportation of NORM;

(3) Development and application of procedures to determine the limits for exempt materials/consignments for transportation according to German Transport Regulations for all NORM.

For the analysis and evaluation of the radiation exposure imposed by shipment of NORM for the following materials, a couple of transport scenarios were defined and the dose to transport workers was calculated.

- Tantalum raw materials;
- Raw phosphate;
- Pipe scales and sludge from oil and gas exploitation;
- Coal ash;
- Waste rock material from uranium mining;
- Zircon raw materials;
- Titanium dioxide raw materials;
- Filter gravel from waterworks.

For calculation of the dose to transport personnel, measured data for radionuclide concentrations in the materials mentioned earlier were used for each transport scenario. The model parameters were either taken or modified from authorized dose calculation procedures related to remediation of uranium mining and milling sites and to disposal of NORM residues together with chemical toxic wastes, or determined by experiment (e.g. relationship between ^{226}Ra and ^{228}Ra activity concentration vs. dose rate at or within a certain distance of the surface of the consignment).

The defined transport scenarios included both the drivers of transport vehicles and the staff involved with loading and unloading. Furthermore, they were divided between scenarios for bulky or unpackaged transport and packaged transport.

It could be demonstrated that only for bulky transport scenarios must the dose due to inhalation of contaminated dust be considered in addition to the external dose by gamma radiation, especially for the loading workers.

Special attention was paid to the dose resulting from transport of materials with non-equilibrium of radionuclides of the uranium-radium decay chain and the thorium decay chain.

Decay chain equilibrium is of particular concern for pipe scales and drilling sludge from oil and gas exploitation where radium isotopes are enriched by chemical processes (co-precipitation with barium as sulfate).

It could be clearly demonstrated that the given 10-fold limit for exempt materials according to TS-R-1 (e.g. 100 Bq/ g for radium isotopes) is only a theoretical limit, because in the case of non-equilibrium, the transportation limit for exemption is derived from the formula given in paragraph 405 of this IAEA regulation (or the relevant national regulation).

As the value of activity concentration for exempt material containing thorium isotopes is lower by a factor of 10 than the value for radium isotopes, ^{210}Pb and ^{210}Po, the limit of activity concentration decisively depends on the share of ^{228}Th (f_{Th228}) in the mixture of nuclides when this formula is applied.

Furthermore, the external dose by γ radiation depends solely on the activity concentration of ^{226}Ra and/or ^{228}Ra independent of the equilibrium status within these two decay chains, because no or only negligible γ-emitters (^{234m}Pa within the uranium-radium chain) occur prior to these radium isotopes.

Therefore, for all scenarios for transport of packaged materials in which only the external dose must be considered, the radium activity concentration is linearly correlated with the dose independent of the kind and the intended use of the shipped material.

Finally, on the basis of the dose calculation results for the transport of NORM, the following recommendations are given to the extent that the proposed dose limit of 0.3 mSv/yr^{-} for transport personnel is accepted.

(1) For bulky transport of NORM with radioactive equilibrium, the five-fold activity concentration for exempt material should meet these requirements independent on the kind and use of such materials.

(2) Accordingly, paragraph 107(e) could be amended as follows:

- Delete the reference to the intended use (i.e., … other than for the extraction of the radionuclides, and that are not intended to be processed for use of these radionuclides…”).
- Furthermore, the last part of the sentence in paragraph 107(e) with the reference to paragraphs 403 to 407 should be replaced by a new paragraph that contains the limits for natural radionuclides only, i.e.:
  - 5 Bq/g for U-nat and Th-nat in case of radioactive equilibrium.
  - In case of radioactive non-equilibrium, the activity concentration for exempt material should be calculated by means of the formula in paragraph 405 of TS-R-1 with the following limitations:
    - 15 Bq/g for ^{226}Ra and 10 Bq/g for ^{228}Ra.
    - The 10-fold exempt limit of 100 Bq/g for ^{210}Pb and ^{210}Po, each in non-equilibrium, is thoroughly applicable regardless of the limitation to 50 Bq/g of each by application of the formula in paragraph 405 of TS-R-1.

4.3.5. Islamic Republic of Iran: Radiological risk assessment of the transport of NORM

Enhanced levels of naturally occurring radionuclides may be associated with certain natural materials, minerals and other resources. Exploitation of these resources and production of consumer items may lead to further enhancement of the radioactivity in the products, by-products, residues or waste arising from the industrial process. A potential outcome is an increase in occupational and public exposures to radiation.

The main objectives of this study as part of the IAEA CRP on the Appropriate Level of Regulatory Control for the Safe Transport of NORM were to determine the radiological characteristics of materials containing naturally occurring radionuclides in the Islamic Republic of Iran and assess, where appropriate, the radiological risk of these transport operations. Initially, data were collected on activity concentrations of naturally occurring radionuclides in material typically transported in the Islamic Republic of Iran.Then the potential radiological exposure associated with the normal transport of these materials was evaluated. The study was undertaken by the National Radiation Protection Department of Iranian Nuclear Regulatory Authority.

The occupational exposure of transport workers has been considered. Assessments have been carried out on the radiological impact of NORM in the following industries:

- Phosphate industry;
- Commercial zircon.

Phosphate industry

The exposure of workers to all steps in a typical transportation scenario has been evaluated. The range of radionuclide concentrations in 161 samples of phosphate rock has been measured. The results are shown in Table 8.

TABLE 8. ACTIVITY CONCENTRATIONS (Bq/g) IN PHOSPHATE ROCK SAMPLES

Radionuclide	**Origin**	**Number of shipments***	**Number of analyzed samples**	**Types of vehicle**	**Mean (Bq/g)**	**Max. (Bq/g)**	**Min. (Bq/g)**
^{232}Th	Morocco	12	84	Ship	0.02	0.06	0.004
^{232}Th	Jordan	11	77	Ship	0.04	0.08	0.004
^{238}U	Morocco	12	84	Ship	1.50	1.80	1.30
^{238}U	Jordan	11	77	Ship	1.14	1.70	0.47
^{40}K	Morocco	12	84	Ship	0.31	0.35	0.29
^{40}K	Jordan	11	77	Ship	0.30	0.50	0.12

* The type of shipment was bulk unpackaged shipment and the amount of phosphate rock was about 30–40 k tons in each shipment

Exposure scenarios

The exposure scenarios by exposed person are shown in Table 9.

TABLE 9. THE EXPOSURE SCENARIOS BY EXPOSED PERSON

2.2.1	Ship crew during off-loading	Occupational exposure
2.2.2	Crane operator during off-loading/transshipment	Occupational exposure
2.2.3	Front end loader operator in ship hold	Occupational exposure
2.2.4	Cleaning crew in ship hold	Occupational exposure
2.2.5	Supervisor	Occupational exposure

Measurement of exposure

Measurement of the external gamma, short-lived alpha-emitting particle (^{222}Rn and daughters) and long lived radionuclide exposure pathways was conducted in those instances where measurement was possible and practical. External gamma measurements were done with two instrument types.

Commercial zircon

Zirconium and zircon are also the raw materials for zirconium metal manufacture. Zircon contains small amounts of uranium, thorium and radium in its crystalline structure. In the Islamic Republic of Iran, the ceramics industry is one of the major consumers of zirconium compounds, which are used as an ingredient, about 10–20% by weight, in glaze. Zirconium compounds are not mined in the Islamic Republic of Iran but mostly imported from Italy, England, South Africa, France, Ukraine and Germany. Natural radioactivity due to the presence of ^{238}U, ^{232}Th and ^{40}K in zirconium compounds was measured by using a gamma spectrometry system with a high pure germanium detector. Activity concentrations of ^{232}Th and ^{238}U in the zirconium compounds range from 0.4 - 0.7 Bq/g and from 2.2 -18 Bq/g, respectively.

The assessment of the external gamma exposure has been carried out only for road truck drivers during a year. Loading of trucks with large bags was carried out by means of a forklift truck in the storage area, and the materials were then transported by road to different facilities at different distances (500- 1500 km) throughout the country. The external gamma exposure dose was measured with thermo-luminescence dosimeters.

Conclusions

The results of this study have been based on actual measured exposures, and the occupational exposure of transport workers has been considered. The doses in all bulk phosphate transport scenarios were less than 20 µSv/shipment. Based on ICRP Publication 60[16], an exposure of the order of a few tens of µSv/annum would not require regulatory control. It is therefore concluded that the occupational exposure risk for bulk phosphate rock transportation is insignificant from a radiological point of view, and exemption levels given in the BSS are appropriate for the transportation of bulk phosphate rock.

The study also showed that the most exposed worker in the transportation of zirconium compounds would receive less than 160 µSv/annum of exposure. It is concluded that these levels are well below all regulatory limits for such activities involving naturally occurring materials, and the transportation of such materials in the Islamic Republic of Iran gives rise to very low radiological consequences.

4.3.6. Israel: Regulatory control of NORM

Background

Israel is one of the world's largest potash and phosphate producers. The annual production is on the order of millions of tons of potash, phosphoric acid and phosphate fertilizers. These products are loaded in the production facilities onto trains and trucks, transported to the two Israeli harbours—Eilat and Ashdod—as unpacked bulk material, unloaded to the harbour warehouses, which contain up to 10,000 tons each, and loaded onto ships. The amount transported ranges from 20–40 tons by truck to several thousand tons by train.

Measurements

Measurements in the first phase were conducted in the loading stage of the phosphate and potash products. They included:

- Measurements of radionuclide content in phosphate and potash products;

- Airborne radionuclide concentrations at the loading facilities;
- Airborne dust size distribution;
- External γ-ray radiation.

Results

The measured results are summarized in Tables 8 and 9. Based on these measurements, the total dose rate for a loading worker was estimated. Also, based on an assumption of the total annual working hours, the annual dose of the loading worker was estimated and compared with the relevant dose limits. For the radionuclides ^{226}Ra, ^{228}Ra, Th-nat and U-nat, it was assumed that each parent nuclide is in secular equilibrium with its progeny, as listed in TS-R-1, Table 2, footnote (b) [13]

TABLE 10. MEASUREMENTS AT THE LOADING STAGE OF THE PHOSPHATE AND POTASH PRODUCTS

Measurement point		**Phosphate fertilizer loading to train**	**GSSP warehouse during truck loading**	**Phosphate ore loading to train (ground level)**
Dust loading (mg/m^3)		5	2	10
AMAD (aerosol median aerodynamic diameter) (μm)		7	4	13
Airborne activity concentration (Bq/m^3)	^{238}U	0.007	0.0025	0.0125 (secular equilibrium)
	^{226}Ra	0.004	0.0012	
Internal dose rate (μSv/h)		0.28	0.13	0.28
External dose rate (μSv/h)		not measured	0.18	0.28
Annual assumed loading hours		500	500	500
Total annual dose (mSv)		0.14	0.15	0.28

TABLE 11. POTASH LOADING (AVERAGE VALUES DURING LOADING PROCESS)

Measurement point	Potash fertilizer loading to train	Potash warehouse during truck loading
Dust loading (mg/m^3)	4.7	5.2
AMAD (aerosol median aerodynamic diameter) (μm)	5.8	6.5
Airborne ^{40}K concentration (Bq/m^3)	0.104	0.072
Internal dose rate (μSv/h)	<0.01	<0.01
External dose rate (μSv/h)	0.20	0.24
Annual assumed loading hours	500	500
Total annual dose (mSv)	0.10	0.12

Each parent nuclide is in secular equilibrium with its progeny, as listed in TS-R-1 (2009) Table 2, footnote (b) [13].

(1). Radionuclide content of products:
- 1.1 ^{40}K content in potash: 15–16 Bq/g;
- 1.2 ^{238}U content in phosphate ore grains: 1.0–1.5 Bq/g (in secular equilibrium);
- 1.3 ^{238}U content in granular simple super phosphate (GSSP): 1.4–1.8 Bq/g; ^{226}Ra content in GSSP: 0.8–1.1 Bq/g.

(2). Measured results and dose assessment at loading points:
- 2.1 Phosphate products loading (average values during loading process);
- 2.2 Potash loading (average values during loading process).

Conclusions

(1). The annual dose to the loading workers at the phosphate and potash facilities in Israel is estimated to be less than 0.3 mSv. It is assumed that the dose to members of the public due to this work is less than 10 μSv per year.

(2). The concentrations of phosphate and potash products are below RS-G-1.7 exemption levels when the additional factor of 10 is included in the graded approach (para. 5.12) [5].

(3). The annual dose assessment for phosphate and potash loading workers indicates that TS-R-1 exemption values are better adopted for loading activities of these materials, including the additional factor of 10 for phosphate and potash.

In addition, reference to the ^{40}K limit in RS-G-1.7 [5] is not appropriate considering the ^{40}K level in KCl salt is on the order of 15–16 Bq/g.

4.3.7. Romania: Risk and safety evaluation in the transportation and disposal of naturally occurring materials-uranium ore and uranium waste in Romania

Main objectives

(1) Identification and evaluation of the potential risks and radiological consequences due to the transport and disposal of the very low-level radioactive materials (NORM)
(2) Examination of the tailing sites in order to determine values of radon population doses that would be more representative of present day and likely future conditions
(3) Assessment of the collective dose factors, air concentration modelling (e.g. modelling of long-range transport, which requires sophisticated models, comprehensive meteorological data and extensive set-up effort), radon source terms, population densities, population dose (exposure) estimation, estimation of the background dose and estimation of the normalized tailings surface area

The contract was carried out for a period of 3 years, starting in 2007. The objectives were divided within every year.

The anticipated outcomes expected were as follows:

(1) The collective doses [person Sv/y] for public and workers; the annual collective doses [person Sv/y], the associated latent cancer fatality risk [probability per year] due to the transport of NORM, in both modes road and train
(2) Long term collective population doses due to radon (considered to mean ^{222}Rn hereinafter) released from abandoned (but stabilized) tailings or from uranium mill tailings
(3) Air dispersion factors (for the model site at 1 km and their reduction with distance [Bq/m^3 per Bq/s]. Dose conversion factors [Sv/h per Bq/m^3]
(4) Collective dose factors directly proportional to the assumed cumulative exposed period of 10 000 Y
(5) Estimation of the radon concentrations based on air dispersion modelling [mBq/m^3] at 1 km distance from the source and at 100 km distance from source
(6) Estimation of the background doses for the people living around the examined sites [person Sv/y].

Results obtained

The potential accident probabilities for road transportation for those three mine locations taken into consideration are as follows.

Crucea: *impact*: 0.435 × E-05/journey; *fire*: 1.53×E-10/journey

Oravita: *impact*: 0.415×E-05/journey; *fire*: 1.21×E-10/journey

Baita: *impact*: 0.430×E-05/journey; *fire*: 1.47×E-10/journey

For rail transportation (for the entire route of transportation) the probability of an accident was determined, based on probability risk assessment, to be 1×E-07, 1 in 10 million. For the evaluation of risk due to uranium landfill sites, the calculated minimum detectable concentrations were as follows.

- ^{222}Rn for air, 37 Bq/m^3;
- ^{226}Ra for water, 0.004 Bq/l; for solids, 3.7 Bq/kg;
- U-nat for water, 0.001 mg/l; for solids, 0.06/T; for urine: 5µg/l.

The results obtained are to be compared with reference values according to the Romanian standards.

External gamma radiation level for the three uranium mine locations are as follows:

Crucea: 0.06 - 0.13 μSv/h;

Oravita: 0.057 - 0.10 μSv/h;

Baita: 0.065 - 0.17 μSv/h;

TABLE 12. LEVEL OF EXTERNAL GAMMA RADIATION FOR THE TRANSPORT OF URANIUM ORE BY ROAD FOLLOWING THE CRUCEA–ARGESTRU RAILWAY STATION ROUTE

No.	**Place**	**Ground (μSv/h)**	**External radiation at 1m (μSv/h)**	**No**	**Place**	**Ground (μSv/h)**	**External radiation at 1m (μSv/h)**
1.	At 0.2km	0.07	0.07	14.	At 6.4 km	0.07	0.08
2.	At 0.7 km	0.06	0.07	15.	At 6.9 km	0.07	0.07
3.	At 1.0 km	0.07	0.07	16.	At 7.4 km	0.09	0.09
4.	At 1.5 km	0.07	0.08	17.	At 7.9 km	0.10	0.08
5.	At 2.0 km	0.07	0.07	18.	At 8.4 km	0.07	0.07
6.	At 2.5 km	0.06	0.05	19.	At 8.9 km	0.07	0.07
7.	At 3.0 km	0.06	0.06	20.	At. 9.4 km	0.07	0.07
8.	At 3.5 km	0.07	0.07	21.	At. 9.9 km	0.08	0.06
9.	At 4.0 km	0.06	0.06	22.	At 10.4 km	0.05	0.05
10.	At 4.7 km	0.10	0.07	23.	At 10.9km	0.06	0.06
11.	At 5.1 km	0.08	0.07	24.	At 11.4 km	0.07	0.08
12.	At 5.2km	0.08	0.06	25.	At 11.9 km	0.07	0.07
13.	At 5.9 km	0.07	0.07	26.	At 12.4 km	0.09	0.07

FIG. 1. Routes of uranium ore transportation in Romania. (as in research report).

Effective dose for workers: No more than 20 mSv/y (at Baita site); collective dose determined: 0.2 mSv/y (estimation made by using IAEA computer code INTERTRAN II and SANDIA computer code RADTRAN 5).

Dispersion factors: External irradiation is (0.5-5 µSv/h); total effective dose of radon in the witness zone is 5.88 mSv and in the impact zone is 15.50 mSv; estimated annual effective dose is lower than 0.2 mSv/y.

Annual effective dose for all radionuclides transferred to the environment was estimated not to exceed 1.4 × E-6 Sv/y.

4.3.8. United Kingdom: A study on the transport of NORM

This study reviewed the transport of materials containing naturally occurring radionuclides in the United Kingdom and, where appropriate, the radiological impact of these transport operations was assessed. Initially, data were collected on activity concentrations of naturally occurring radionuclides in material typically transported in the United Kingdom; second, the radiation exposures that may result from the transport of NORM in the United Kingdom were estimated.

Activity concentrations of materials containing NORM

Industrial uses

Natural materials are extracted and used for a number of industrial processes. In some of these operations, the natural radionuclides can become further concentrated as a result of chemical processes. The main NORM materials that are transported in the United Kingdom are described below.

1. Coal and coal ash—Radionuclide concentrations in UK coal are low, the typical activity concentration of ^{226}Ra being 0.015 Bq/g [17]. Average concentrations in ash ranged from 0.01 to 0.10 Bq/g for ^{226}Ra and from 0.053 - 0.094 Bq/g for ^{232}Th [18]; [19]). Activity concentrations of ^{210}Pb and ^{210}Po can be higher, up to 2 Bq/ g [18].
2. Iron and steel production—Iron ore, limestone and coal used in this industry contain low levels of natural radionuclides, even though concentrations of radionuclides in the fuel ash, slag and dust from the sintering process can be higher. Iron ore contains ^{238}U at a concentration of about 0.015 Bq/g) [20]. Typical concentrations of natural radionuclides in the wastes [21] are ^{238}U: 0.9 Bq/ g; ^{226}Ra: 0.9 Bq/ g; ^{228}Ra: 0.45 Bq/g and ^{235}U 0.04 Bq/g^{-}. Activity concentrations in slag are one order of magnitude lower.
3. Building materials—Typical activity concentrations of ^{226}Ra and ^{232}Th in building materials range from 0.033 - 0.7 Bq/g and 0.015 to 0.17 Bq/g, respectively [22].
4. Potash, phosphate rock and fertilizers—More than one million tons of potash (95% potassium chloride) are mined in the United Kingdom each year, mainly for use in the fertilizer industry [23]. The concentration of ^{40}K in potash is about 15 Bq/g. The processing of phosphate rock has now ceased in the United Kingdom [24].
5. Ores and mineral sands—a number of ores and minerals used in various industrial processes contain relatively high concentrations of natural radionuclides. These include baddeleyite, from which refractory bricks for high-temperature furnaces containing zircon are manufactured (a few hundred tons of bricks are produced in the United Kingdom each year in a total of some 2000 tons of refractory material) [25]. They also include ilmenite and rutile, from which the pigment titanium dioxide is extracted. Zircon sand and flour are also used in a number of industries, for example for producing refractory bricks and ceramic glazes and for high-temperature casting. Activity concentrations of ^{232}Th and ^{238}U in these materials ranged from 0.2 - 5 Bq/ g and from 0.1 to 10 Bq/ g, respectively. In the United Kingdom, there is now no large-scale importing or processing of, and little or no use of, minerals such as pyrochlore, monazite and tantalite, all of which have relatively high concentrations of natural radionuclides.
6. Wastes from the oil, gas and China clay industries:

   - Oil industry—Oil extraction from installations in the seas around the United Kingdom can result in the deposition of scales on pipe work and other equipment. Radium from the rocks of the sea bed also precipitates within pipework and other components of the extraction process. The equipment is descaled or replaced at regular intervals; therefore, there is no significant build-up of ^{210}Pb and ^{210}Po. Much of the scale is removed and disposed of offshore, but equipment that cannot be descaled is brought to a descaling plant in Scotland or to the south of England. The scale waste is processed and discharged to the sea. The items consigned from the platforms to the onshore descaling companies consist of pipes, pumps, valves and flexible hoses [26]. Typical activity concentrations of ^{226}Ra are around 40 Bq/g, even though they can go up to a few thousand Bq/g) [27]. There were 340 consignments during 2007, only 4 being transported as excepted packages.
   - Gas industry-Natural gas from the gas fields around the United Kingdom contains radon (^{222}Rn) and its decay products ^{210}Pb and ^{210}Po. These radionuclides deposit on the equipment used to process the natural gas as thin coatings or "black

sludges.” Activity concentrations of ^{210}Pb and ^{210}Po are very variable and can range up to a few thousand Bq/g

- China clay industry—Kaolinite is extracted from the granite rocks of southwest England for the production of China clay, which is used in the manufacture of porcelain and paper and in medicinal products. The raw material contains uranium and thorium and their decay products. The use of sodium hydroxide and sulphuric acid during the refining process results in the precipitation of barium sulphate scale; radium, ^{210}Pb and ^{210}Po are also found in the scale. Since 1996, a purpose-built facility removes scale from used equipment so that the metal can be recycled and the waste scale can be disposed of appropriately [28]. Maximum surface dose rates on pipes in a few consignments were in the range 10 to 50 µSv/h. In each consignment, there are some 10 to 20 items that are transported as surface contaminated objects (SCO-I). These are wrapped in polythene sheets to prevent any loss of the internal contamination during transport. During 2007, there were 80 such consignments. The water and the suspended solids used to remove scales at the facility are collected into a settling tank, and the slurry formed after the water is extracted is mixed with cement and stored in steel drums. Activity concentrations of naturally occurring radionuclides in the cemented waste are low (^{226}Ra < 2 Bq g; ^{210}Pb and ^{210}Po: 0.2 Bq /g^{-}; ^{228}Ra and ^{228}Th < 0.5 Bq/ g; ^{238}U: < 0.06 Bq/ g; ^{234}U and ^{232}Th < 0.07 Bq/ g). Radionuclide concentrations are well below the relevant exemption values. The drums are loaded into a skip that is used to take them to a landfill site for disposal. In recent years, two consignments of 55 drums each have been taken each year for disposal.

Exposures of workers and members of the public

Material outside the scope of the regulations

A generic assessment was carried out to estimate the radiation doses received by workers and members of the public during transport of zircon flour. This was done to illustrate the likely level of radiation exposures associated with the transport of materials with radionuclide concentrations around or slightly above the exemption concentration values, but less than a factor of 10 above those values. It was assumed that this material is carried in sacks on a truck in a load of 20 tons. The annual dose received by the driver was calculated using a very conservative annual driving time (with a full load) of 600 h. It was assumed that the parent radionuclides are in secular equilibrium with their decay products. The dose rate in the driver’s cab, calculated using Microshield [29] was about 0.3 µSv/ h, which gives an annual dose of 0.18 mSv. A member of the public was assumed to be exposed near a truck for about 1 minute per week, or about 1 h per year. The dose rate at 5 m from the side of the truck was calculated to be 0.04 µSv/ h, which gives an annual dose of 0.04 µSv.

Equipment contaminated with oilfield scale

The external surface dose rates close to these items are very low; a surface dose rate of 3.2 µSv/h was calculated using Microshield [29], on the basis of an activity concentration of radium of 40 Bq/g. For a consignment of 20 pipes, the dose rate in the driver’s cab was calculated to be 0.07 µSv/ h. Using a very conservative annual driving time of 600 h, this gives rise to an annual dose of about 40 µSv. This is consistent with experience as workers involved in transporting these items do not receive any measurable annual doses. The annual dose to any member of the public from such consignments was calculated to be 0.008 µSv.

This value was based on a dose rate at 5 m from such a consignment calculated to be 0.008 µSv hand assuming a member of the public is exposed for about 1 minute a week.

Equipment contaminated with China clay scales

The dose rate in a driver's cab while transporting a typical load of pipes contaminated with China clay scales is about 1 µSv/h, based on dose rate measurements made around a freight container. With 80 journeys a year, each taking about 1 h, the annual dose is 80 µSv. This is consistent with dosimetry results for workers at the facility who typically receive a maximum of 0.2 mSv/y from loading, unloading and driving the consignments. The measurements indicated that the dose rate at 5 m from the side of a typical consignment is in the order of 0.1 µSv/h. Assuming a member of the public is exposed to such a vehicle for about 1 minute a week, the annual dose is about 0.1 µSv. Drums containing cemented waste are carried to a disposal site in a skip, which is loaded onto a truck. The dose rate at the surface of the skip is typically 1.5 µSv/ hand about 0.1 µSv/ hat the position of the driver. Two loads of 55 drums are currently transported annually. Assuming a loading and unloading time of 4 h and a driving time of 1.5 h, the annual dose to such a driver would be less than 3 µSv. The dose rates at a few metres from the skip are very low, and its movement to the disposal site would result in annual doses to members of the public of much less than1 µSv.

4.3.9. United States of America

The research undertaken by the United States of America as part of the CRP on the Appropriate Level of Regulatory Control for the Safe Transport of NORM included evaluation of the following:

- Inconsistencies in the application of the exempt activity concentrations, particularly as they are applied on the basis of the intended use of the material being transported (e.g. paragraph 107(e) of the Transport Regulations, TS-R-1)
- Measured and estimated doses associated with the transport of uranium ore and other NORM
- Treatment of progeny (daughter products) in TS-R-1, Table 2, footnotes (a) and (b).

Below are summaries of the results of the US activities in each of these areas.

Evaluation of inconsistencies in the application of the exempt activity concentrations

The report by Rawl, Leggett and Cook [30] examined the basis for the current exemption system for NORM and its consistency with the guiding principles of the IAEA BSS, with emphasis on the special provisions in paragraph 107(e). This paragraph provides an exemption (i.e., the transport regulations do not apply) for NORM material that will not be and has not been processed for removal of the radionuclides, provided that the activity concentration does not exceed 10 times the exempt activity concentration value listed in Table 2 of TS-R-1. It arrived at the following conclusions.

- The 10× 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 10× 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.

- Realistic transport scenarios were identified in which the provisions of paragraph 107(e), together with the rounding methods used to establish the exemption values, led to exemption values differing by two orders of magnitude for two materials that emit the same types and energies of radiation and deliver the same dose per unit activity concentration to the person presumed to receive the highest dose. This is inconsistent with the principle that the exemption values should be risk-based.

In addition, Rawl, Leggett and Cook [30] evaluated the special provisions in paragraph 107(e), regarding the PIU restriction concluding the following.

- 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 PIU 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 corollary clause from the definition of LSA-I. This definition includes "uranium and thorium ores and concentrates of such ores and other ores containing naturally occurring radionuclides which are intended to be processed for the use of these radionuclides."

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 NORM from regulatory control. The restriction does not appear to have a practical basis; and as illustrated by Leggett, Rawl and Cook (2007) [25], it introduces unnecessary complexity and cost into transport of these materials without reducing risk from transport. Also, it violates the principle underlying the BSS exemption system in that it is not dose-based. From a radiation protection perspective, any restriction of the 10× provision in paragraph 107(e) should be justified on the basis of projected doses during transport.

Evaluation of measured and estimated doses associated with the transport of ore containing NORM

The purpose of the report by Rawl, Scofield, Leggett and Eckerman [31] was to examine whether the PIU provision in paragraph 107(e) has a valid radiation protection basis. To make this evaluation, the report focused on ores that contained uranium and compared doses associated with the transport of ores and products that were PIU with similar ores and products with NPIU of radionuclides. The conclusions from this report were as follows.

- NPIU mineral ores and products dominated the 1 -10 Bq/g range. However, there were some alternate feed materials (PIU) that had activity concentrations in the 1 to 10 Bq/g range. Copper and vanadium ores from which uranium was extracted (PIU) had uranium activity concentrations close to the 1 - 10 Bq /g category.
- The greater than 10 Bq /g category primarily contained ores and products intended for use of radionuclides (PIU); however, there were a couple of NPIU products also within this category, (e.g. tantalite and copper concentrate).

- Derived activity concentrations that resulted in an annual dose of 10 µSv (based on a normalized 400 h driver exposure time) ranged between 0.2 and 14 Bq/g regardless of PIU.
- Ores and products such as copper and vanadium that are co-mined or produced as a by-product of uranium ore processing, and alternate feed materials transported to uranium mills, are most impacted by the PIU restriction. In this case, all transport segments are potentially regulated (before and after uranium extraction).

The PIU restriction implies either that past or future extraction of radionuclides from a material 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 time and distance). Neither situation appears to be occurring. There does not appear to be a sound technical basis for maintaining the intended use restriction. Therefore, natural material and ores containing naturally occurring radionuclides that either are in their natural state or have been processed (both PIU and NPIU), provided the activity concentration of the material does not exceed 10 times the values specified in Table 2 of TS-R-1, should be included in paragraph 107(e) because doses are similar regardless of intended use.

Evaluation of decay chains in TS-R-1 Table 2, Footnotes (a) and (b)

Table 2 of TS-R-1 provides activity limits (A_1 and A_2 values) for individual radionuclides in Type A packages, exempt activity concentrations and activity limits for exempt consignments. Table 2 includes footnotes (a) and (b) that provide information regarding the decay chains included in the calculation of the numerical values. Footnote (a) denotes those radionuclides for which the A_1 and A_2 values include the contributions from daughter products with half-lives of less than 10 days. Footnote (b) denotes those radionuclides for which the exemption values include the contributions from daughter products and the identity of the progeny that are considered in secular equilibrium. However, the two footnotes differ with no explanation.

Several observations are noted in the US research report regarding footnotes (a) and (b) of Table 2. There were a number of cases when progeny were ignored in footnote (b) because of low yields. In addition, there were cases in which the branching fractions for selected progeny in the footnotes differed from branching fractions defined in ICRP Publication 107[32].

Based on this evaluation, it was recommended that the footnotes be revised as follows.

- If a radionuclide is listed with a footnote (b) for its exemption values, then it need not also be listed with a footnote (a); consequently, radionuclides with a footnote (b) should have the footnote for their A values changed from (a) to (b). This would indicate the same physical information was used in deriving the limits.
- Future efforts to rationalize the treatment of daughter products in the two calculation systems (A values and exemption values) should be based on ICRP Publication 107[32].

5. CONCLUSIONS

The following conclusions were agreed upon at the final (third) RCM meeting, 16-20 November 2009.

(1) The doses to personnel involved in transport operations (drivers and loaders) calculated by participants to the CRP were found to be within the range described in the regulatory context.

(2) The doses to the general public calculated by participants in the CRP were at least an order of magnitude lower than the doses to personnel involved in transport operations. Derived activity concentrations of NORM that result in an annual dose of 10 µSv (based on a normalized 400 h driver exposure time) ranged between 0.2 and 14 Bq/g regardless of prior or intended use. Therefore, a factor of 10 applied to the activity concentration for exempt material in Table 1 of the IAEA TS-R-1 Safety Requirements, 2009 Edition [13], although conservative, may be considered adequate to exempt NORM in secular equilibrium from the transport regulations;

(3) An activity concentration of 1 Bq/g is appropriate as the basic exemption value for U-nat and Th-nat, and the provision for the activity concentrations of NORM not to exceed 10 times the values specified in Table 2 of TS-R-1 (2009)[13] as specified in paragraph 107(e) of TS-R-1 (2009) [1] was both appropriate and necessary.

(4) An exemption value for ^{40}K of 10 Bq/g may be too restrictive, given the ratio of this isotope to stable potassium in the natural environment.

(5) There was agreement with all represented countries, except France, that the language "intended to be processed for the use of these radionuclides" of NORM restriction in paragraphs 107(e) and para 409 be removed and replaced with the following suggested text.

These Regulations do not apply to:

> Paragraph 107. (e) Natural material and ores containing naturally occurring radionuclides which are either in their natural state or have been processed, provided the activity concentration of the material does not exceed 10 times the values specified in Table 2, or calculated in accordance with paragraphs 403–407;
>
> 409. LSA material shall be in one of three groups:
>
> (a) LSA-I
>
> (i) Uranium and thorium ores and concentrates of such ores and other ores containing naturally occurring radionuclides which exceed the values specified in paragraph 107(e);
>
> (ii) Natural uranium, depleted uranium, natural thorium or their compounds or mixtures, that are unirradiated and in solid or liquid form;

(6) The provision that the activity concentrations of NORM not exceed 10 times the values specified in Table 2 of TS-R-1 (2009) [13], as specified in paragraph 107(e) of TS-R-1 (2009) [1], should be made clearer to ensure its effective application. Options suggested by participants to the CRP include the addition of a footnote to the entries for ^{40}K, Th-nat and U-nat referring to paragraph 107(e).

(7) The need to apply paragraph 405 of TS-R-1 (2009) [13] to radionuclides that are not in secular equilibrium should also be clearer. This requirement is best illustrated by radium isotopes that have been separated from the decay chain of their parent. The exemption value of 10 Bq/g for ^{226}Ra and ^{228}Ra may be too high when the rule for mixtures is not applied.

Recommendations from this Coordinated Research Project are reflected in the 2012 Edition of the Transport Regulations. These requirements, approved by the Board of Governors in March 2012 are now published. Excerpts from the regulations and companion guidance material are outlined below.

Transport Regulations, TS-R-1, 2012 Edition, Paragraph 107. "These Regulations do not apply to any of the following:

(f) Natural material and ores containing naturally occurring radionuclides, which may have been processed, provided the activity concentration of the material does not exceed 10 times the values specified in Table 2, or calculated in accordance with paras 403(a) and 404–407. For natural materials and ores containing naturally occurring radionuclides that are not in secular equilibrium the calculation of the activity concentration shall be performed in accordance with para. 405".

Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition) TS-G-1.1 [33].
"Para 107.4. The scope of the Transport Regulations does not include ores and natural or processed materials containing naturally occurring radionuclides provided that the activity concentration of the materials does not exceed 10 times the exempt activity concentration values (Table 2 or calculated in accordance to paras 403–407).

Following the conclusion of the IAEA Coordinated Research Program (CRP) on transport of NORM [2], it was agreed that this exclusion does not depend on the prior or intended use of the material, i.e., whether it is to be used for its radioactive, fissile or fertile radionuclides or not. The CRP modelling and analysis of realistic transport scenarios found that in cases when the provision of 10 times the exempt activity concentration values for this material is applied, the maximum annual dose from unregulated transport of the material would generally be substantially less than 1 mSv (Referring to para. 71 of ICRP 104, an annual dose criterion of 10 μSv does not apply to exposure situations involving natural sources, as this value is one or two orders of magnitude at least below the variability of the natural radiation background). The new BSS (IAEA Draft Safety Requirements DS 379) sets an annual dose criterion of 1 mSv for exemption for NORMs. The CRP concluded that the exclusion is appropriate from a radiological protection consideration and from a risk based regulatory consideration since the potential radiological dose from the material during transport is dependent on the activity concentration of the material. Guidance for determining activity levels and basic nuclide values is provided in paras 403–407 for reference in use of Table 2.

For ores and other natural or processed materials containing natural occurring radionuclide of uranium-radium and / or thorium decay chain, the basic nuclide values for exempt activity concentration as given in Table 2 for U(nat) and Th(nat) can only be used if the radionuclides are in secular equilibrium. If this is not the case, that means that due to processing activities such as chemical leaching or thermal treatment the natural radioactive equilibrium state does not exist and the formula for mixtures of radionuclides according to para. 405 has to be applied to calculate the exempt activity concentration.

As the value of activity concentration for exempt material of TS-R-1, Table 2 e. g. for Th-228 activity concentration is by a factor 10 lower than this for the isotopes Ra-226 and Ra-228 as well as Pb-210 and Po-210, the limit of activity concentration decisively depends on the fraction of Th-228 (fTh228) in nuclides mixture, when applying the formula in para. 405.

This issue is depicted at the following example:

In the process of extraction of crude oil and natural gas, scaling takes place at the inner walls of the production pipes. The scales consist in most cases of barium sulphate in which radium isotopes co-precipitate, while the parent nuclides (U-228, Th-232) do not occur in the deposit. Accordingly the secular equilibrium of the U-Ra decay chain and / or Th decay chain is disturbed. While Pb-210 and Po-210 are slowly re-growing from Ra-226 (the equilibrium is reached after about 100 years) Th-228 re-grows from Ra-228 with a so called “flowing equilibrium” within few years. Therefore the fraction of Th-228 of the total activity is increasing with time (reaching equilibrium of 1.46 times Ra-228 activity concentration). The insertion of measured activity concentrations as provided in German report [3] into the formula of para. 405 leads to the following exempt activity concentration (sum activity):

(fRa226 + fPb210 + fPo210 + fRa228) = 0.84 while fTh228 = 0.16

From this it follows that (0.84)/10 + 0.16/1 = 0.244, and next 1/0.244 = 4.1 Bq/g as exempt activity concentration, i.e. the sum activity of all relevant nuclides. This value can now be multiplied by 10 according to para. 107 f), while the specific activity of each radionuclide is given by its fraction.

However, there are ores in nature where the activity concentration is much higher than the exemption values. The regular transport of these ores may require consideration of radiation protection measures. Hence, a factor of 10 times the exemption values for activity concentration was chosen as providing an appropriate balance between the radiological protection concerns and the practical inconvenience of regulating large quantities of material with low activity concentrations of naturally occurring radionuclides.”

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