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Negative effects of using transport definition classifications of radioactive material in lieu of impact assessments

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Abstract

In a region with no commercial nuclear industry and a low population density such as Australia, health physics has limited opportunity to develop as a dedicated role in many sectors including medical, health & safety and resources.

This sparsity of *professional* radiation specialists and health physicists leads many non-nuclear industries, and in some cases regulators, to grasp at oversimplified models when defining acceptable practices with radioactive material. These include models such as the linear no-threshold model (LNT) at very low exposure rates and IAEA (SSR-6) definitions of radioactive material during transport as a proxy for radiological risk.

The models, while applicable for the transport of competently prepared Class-7 dangerous goods packages, do not adequately assess the risk from sources such as low specific activity (LSA) and surface contaminated objects (SCO) that may not be legally defined radioactive sources during transport. These may pose a significant radiological risk, such as when transport regulations drive health and environmental protection, i.e. disposal and bioaccumulation.

Introduction

The International Atomic Energy Agency Regulations for the safe transport of radioactive material, Specific Safety Requirements SSR-6 and it's various adoptions by IATA, IMO and member states is the primary resource for transport. The scope of SSR-6 is to "provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment that are associated with the transport of radioactive material" (SSR-6, c101).

In principle, all materials can either be classified as radioactive or not radioactive for transport. The criteria are the material meeting the activity Bq and activity concentrations Bq/g (columns 4 and 5) of the basic radionuclide values in Table 2 of SSR-6.

Material and consignments that don't meet these criteria are considered *exempt* from the transport requirements. At no point does SSR-6 state that the material, source or consignment is *without* an associated radioactive hazard, only that the material does not contain sufficient total activity or activity concentration to be considered radioactive during transport.

Two examples of this definition based on total activity and activity concentration are the Am-241 sources within residential smoke detectors and transport of NORM containing ore. Smoke detectors have a very high concentration (Bq/g) Am-241 source however the source is, by design, 37,000 Bq, below the 40,000 Bq exempt limit for Am-241. So while exempt from the requirements of SSR-6 during transport, the source capsule, should it be removed from the device may present a significant radiological hazard, especially if ingested.

Mining ore on the other hand, for instance, a 20,000 kgs trailer of mineral sands concentration (Th-nat) may contain a significant total activity, however not exceed the Th-nat exemption limit of 10 Bq/g.

The allure of SSR-6 and its various implementations is the firm and unambiguous definitions used, the exact number above or below, which have very specific outcomes and strong compliance language used throughout. SSR-6 even has a defined amount of activity on the surface of a package that is considered *contamination* (SSR-6 c214).

One key general feature of all consignments in transport, whether they be radioactive or not, is that they are contained within a vessel, package or instrument, and the pathways for the material to present a radiological hazard are limited to gamma and neutron irradiation.

Application of these compliance requirements and definitions begins to fail with non-transport scenarios, and this paper will discuss the over and under-representation of radiological risk using these methods, their consequences in a jurisdiction with a small nuclear sector, but a significant resource (mining and oil & gas) sector.

Risk assessment tools

Any risk assessment of radiation or radioactive material must include all potential pathways for isotopes to enter the body, the method of entry and how the body processes the isotope and the type(s) of radiation the isotope emits that may cause damage or harm

Several risk assessment tools are available to assess the health and safety impact of radioactive material that is present or mobile within the workplace or environment. They are developed and supported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Committee on Radiological Protection (ICRP).

ICRP Publication 137 Occupational Intakes of Radionuclides: Part 3 provides dose conversion factors (DCF) for a host of isotopes to assess intake of activity and dose; however, this is greatly dependent on the exposure pathway. For instance, the intake via inhalation of Thorium containing dust (natural, all progeny present) as dust particles of 1 or 5 microns is 8.46×10^{-5} Sv/Bq and 4.82×10^{-5} Sv/Bq respectively. The variation is due to the smaller particles being able to travel further into the lung and ionise softer tissue and the contribution of the progeny to the committed dose (Table 1), another factor not necessarily considered once the material has been deemed not radioactive.

Table 1 Thorium-232 decay and its progeny dose conversion factors

Radionuclide	Decay	Dose coefficient (Sv/Bq)	Inhaled (Bq)		Dose (Sv per Bq)
			Alpha	Beta	
^{232}Th	a	1.20E-05	1		1.20E-05
^{228}Ra	b	1.70E-06		1	1.70E-06
^{228}Ac	b	1.20E-08		1	1.20E-08
^{228}Th	a	3.20E-05	1		3.20E-05
^{224}Ra	a	2.40E-06	1		2.40E-06
^{220}Rn*	a		1		
^{216}Po*	a		1		
^{212}Pb*	b	3.30E-08		1	3.30E-08
^{212}Bi*	64.1% b 35.9% a	0.000000039	0.359	0.641	3.90E-08
^{212}Po*	a		0.641	0.359	
^{208}Tl*	b				
			6	4	4.82E-05

Ultimately the level of risk is not determined by the activity of radioactive material present, though this is a factor. The risk to workers, members of the public or the environment is the dose (Sv) that the target will receive. For instance, the risk profile of the smoke detector source dramatically increases with the introduction of an inhalation pathway. Inhalation allows the alpha-emitting Am-241 to damage the lung walls, and it is a scenario not directly considered when determining if it is exempt material or not.

For modelling environmental effects of radioactive discharges into the environment, a publicly available tool Environmental Risk from Ionising Contaminants Assessment (ERICA) exists. It was designed to model the dispersion and concentration via bioaccumulation of nuclides in target receptors in an environment.

Typically environmental assessments require extensive sampling of flora and fauna before any activities take place to determine ‘natural’ levels of isotopes within the target, then measure the bioaccumulation of isotopes over time. The whole process can span years and involve the sampling of thousands of plants and animals looking for accumulation in a particular plant or animal, similar to that of mercury in fish.

It is common for material that is well below the exempt levels of radioactive to have an associated exposure well above one mSv per year.

The regulatory landscape in Australia

This paper shall focus on the radiation safety legislation within Australia as a Commonwealth jurisdiction, and the states and territories within, each with its stakeholders and industrial drivers determining what aspects of radiation safety get addressed and to what depth.

Nationally Australia has adopted the IAEA and ICRP codes verbatim to align its import and transport with international conventions from IATA for air cargo and IMO for sea transport. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has jurisdiction over Commonwealth interests and organisations (customs, defence, the only research reactor operating in Australia) but no jurisdiction within the states or territories of Australia.

Within the states and territories, the regulator may be either the Department of Health or the Environmental Protection Agency, depending on the state or territory. The inconsistency with the statutory authority responsible for radiation safety can lead to a significantly different approach in each state or territory in licencing and compliance.

States such as Western Australia, Northern Territory and Queensland are major mining centres of Australia and as such, have specific legislation regarding NORM in mining. In Western Australia, a mine site that either has radioactive material OR a radiological hazard associated with its activities will be subject to two different acts, the Radiation Safety Act for licencing etc. and the Mines Safety and Inspection Act, for worker safety and health. The requirements of these acts do not necessarily align when the material in question borders on being exempt or not.

One confusing outcome of the transport of heavy mineral concentrate (HMC) from the titanium dioxide mining industry in Western Australia is the placarding of consignments and registration/licensing of storage facilities.

The transport of radioactive material in Western Australia is as per the 2008 ARPANSA transport code (enacted in legislation to that specific year) however storage and the definition of radioactive material is as per an overwriting definition of 30 Bq/g (all progeny accounted for). This definition was established to capture unsealed stockpiles of NORM bearing mining products form the titanium dioxide mining industry.

While in secular equilibrium, a truckload of HMC containing Th-nat with head of chain activity of 4 Bq/g would be exempt under SSR-6 c107 however, the 4 Bq/g contribution from all 9 isotopes in the Thorium-232 decay chain (Table 1) would give a combined activity concentration of 36 Bq/g which exceeds the state definition of a radioactive material. Ergo the material is radioactive when stopped for more than 24 hours and requires placards and storage of radioactive material controls, but then stops being radioactive once the trailer begins moving.

> This demonstrates how the transport codes definition of exempt may leads to non-compliance in certain jurisdictions and does not provide a tangible assessment of risk.

Surface contamination

SSR-6 has a very specific definition of *contamination* based on the types of emission and the radio toxicology of the isotopes involved:

> SSR-6 c214. Contamination shall mean the presence of a radioactive substance on a surface in quantities in excess of 0.4 Bq/cm2 for beta and gamma emitters and low toxicity alpha emitters, or 0.04 Bq/cm2 for all other alpha emitters.

When determining if a package, for instance, a Type-A and Type-B sealed source container within which is an isotope not normally found (Cf-252, Cs-137, Ir-192 etc.) this definition may be useful to determine if the containment system has failed and radioactive material is leaching, sifting or otherwise permeating the containment system barriers.

Table 2 Simplified surface contamination model

Surface area	300	cm2	As per SSR-6 c214
Depth	0.05	cm	Assumed self-attenuation limit
Volume	15	cm3	
Density (granite)	2.75	g/cm3	Worldwide average (Wikipedia)
Mass	41.25	g	
Darling Scarp model			
	Lower	Upper	
Typical U	0.011	0.022	Bq/g (Alach, 1996)
Surface activity U	0.454	0.908	Bq
Average surface U	0.002	0.003	Bq/cm2
α dps U	0.0121	0.0242	Total alpha decays per cm2
Typical Th Bq/g	0.053	0.5	Bq/g (Alach, 1996)
Surface activity Th	2.19	20.63	Bq
Average surface Th	0.01	0.07	Bq/cm2
α dps Th	0.04	0.41	Total alpha decays per cm2
Combined surf act	0.01	0.07	Bq/g

The model in Table 2 shows the potential alpha detections per second from a 300 cm2 section of granite outcropping along the residentially populated 400km Darling Scarp in Western Australia. While mostly below the definition of contaminated, it can be seen that using the SSR-6 definition of 'contaminated' without context of what is being measured can lead to significantly different assessments of risk and rocks that are currently parts of homes, public spaces and semi-permanently occupied infrastructure suddenly become dangerous goods for transport as UN2913 surface contaminated objects.

This application of the contamination definition and the subsequent imposed transport and disposal limitations is being applied across Australia by private sector consultants to the resources sector.

Specific activity

The IAEA technical document IAEA-TECDOC-1712 *Management of NORM residues* has the following to say regarding exemption:

> The regulatory body may decide that the optimum regulatory option is not to apply regulatory requirements to the legal person responsible for the material. The mechanism for implementing such a decision is the granting of an exemption. As a general criterion, exemption may be granted if either of the following conditions is met [19]:
>
> a) Radiation risks arising from the practice or a source within a practice are (and are likely to remain) sufficiently low as not to warrant regulatory control; or
>
> b) Regulatory control of the practice or the source would yield no net benefit, in that no reasonable control measures would achieve a worthwhile return in terms of reduction of individual doses or of health risks.

It goes on to discuss exemption as a function of dose to people and the environment and at no time suggests the concentration of the material as a criterion to determine exemption.

Table 3 Yangibana uranium and thorium content at ore body

	Uranium ppm (Bq/g)			Thorium ppm (Bq/g)		
	Average	Max	Min	Average	Max	Min
Bald Hill	10.2 (0.12)	44.6 (0.54)	2.4 (0.03)	142.8 **(0.59)**	1134.5 **(4.71)**	18.1 (0.08)
Frasers	6.7 (0.08)	14.1 (0.17)	1.9 (0.02)	52.5 (0.22)	132.7 (0.55)	20.2 (0.08)
Yangibana	10.7 (0.13)	26.4 (0.32)	2.5 (0.03)	321.6 **(1.33)**	1472.5 **(6.11)**	21.4 (0.09)

(Yangibana, 2018)

Figure 1 Radioactive store for rock samples in an area with ore body outcroppings of 4 μSv/Hr

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c) Radiation risks arising from the practice or a source within a practice are (and are likely to remain) sufficiently low as not to warrant regulatory control; or

d) Regulatory control of the practice or the source would yield no net benefit, in that no reasonable control measures would achieve a worthwhile return in terms of reduction of individual doses or of health risks.

It goes on to discuss exemption as a function of dose to people and the environment and at no time suggests the concentration of the material as a criterion to determine exemption.

Table 3, naturally occurring rock can exceed the transport exemption limits, meeting the transport definition of radioactive material. In the case of the Yangibana rare earth element project, these thorium bearing rocks are (and have been for millennia) surface exposed rock.

The entire area is pastoral land, and no radiation impact assessment requested until it became a potential mining operation. As the thorium and uranium are hosted in hard rock matrix with little mobility in the environment as a leachable contaminant or airborne dust, the impact of the rock in-situ is negligible.

The impact of the thorium and uranium in the hosted rock, however, becomes significantly more pronounced when mining begins, and the rock is blasted, milled and hauled. During this active mining phase of the project, the properties of the rock have not changed, nor it's classification under transport rules.

It is only via an occupational hygiene study assessing the pathways and intake that the risk can be determined. To demonstrate, assume the mining operation produces 5-micron AMAD dust with a thorium concentration of 0.5 Bq/g, this rock would not be a prescribed material and exempt under almost all requirements.

The committed dose to workers from the thorium and progeny a combined dose conversion factor of 8.46×10^{-5} Sv per Bq (DMP, 2010) over 2000 hours with a breathing rate of 1.2 m^3 per hour in a 1 mg/m^3 dust environment would be 101 µSv. While not a significant annual dose, contributes to the total occupational exposure of the worker, and there is no way to derive that risk from transport requirements alone.

The mining industry is generally mature enough to be aware of the dose assessment methods to accurately model the exposure to workers and project future exposure based on changes in working conditions.

The oil & gas industry & TENORM

In the last two decades, technologically enhanced naturally occurring radioactive material (TENORM) in Australias oil and gas industry has come to the forefront of safety and environmental concerns. It's detection and subsequent concerns by workers as urged the industry to find solutions to the problem on a risk-based platform.

TENORM if generally formed by the removal of fluids within high temperature and high-pressure oil or gas reservoir that has dissolved radium isotopes (Ra-226 and Ra-228) in the produced fluids or the removal of radon gas with the gas stream. As these fluids and gases reach either seabed or surface infrastructure, they cool and the dissolved radium precipitates as scale or the gas condensate as radon progeny.

The challenges to the oil & gas sectors risk assessment related to TENORM are that they cannot easily inspect the infrastructure, or it is inside the subsea infrastructure, shielded be its own wall thickness or underneath the seabed floor and inaccessible.

As a sector typically filled with petroleum and mechatronics engineers, their design philosophy has typically been "find the appropriate ISO, DNV or Australian Standard and follow it" to reduce personal and company liability should the design fail. The focus is typically very *material specification* focussed, that is the intrinsic property of the material without regard to occupational disease risks, in this case, radiation exposure pathways.

Industrial packages and UN rated drums

The purpose of SSR-6 is to 'provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment that are associated with the transport of radioactive material' (SSR-6, c101). The requirements of packaging do not incorporate containment beyond reasonable transport and intermittent storage durations.

An example of this is Type-A packages used for nuclear gauge process control. While it is common for a nuclear gauge design also to meet Type-A packaging requirements (to allow transport for the sealed source without removal from the gauge housing,)a compliant Type-A package does not necessarily meet the requirements of a nuclear gauge.

Design and use of a nuclear gauge must incorporate the environment (weather, industrial process, exposure to corrosive agents, subsea, etc.) and the duration of installation before it is selected. This duration can be up to 15 years, and it is captured in the nuclear gauge design and construction requirements, not the Type-A package requirements.

While it is common practice globally to store both hazardous and non-hazardous materials in steel drums, this practice can have varying results based on factors such as environment, the material being stored and handling methods employed.

In mining, the disposal of NORM residues is generally an immediate return to the source (mine pit) which can be executed during the mining operations, or via a constructed tails storage facility (TSF). The TSF must be designed to capture and retain all hazardous and non-hazardous material contained within.

Oil and gas installations do not have the option of mine pits or TSFs to return generated TENORM scale and the only access to the ‘source’ is via a limited number of hydrocarbon production wells. Reinjection of any fluids containing solid particle into the reservoirs via these wells has the potential to restrict the flow of out of a producing well or restrict the injection of water/brine into a reinjection well.

An oil and gas facility that has either TENORM sands in their production fluids or recovered scale from production equipment is left with material for which they must find an alternative disposal option.

Steel drums (often refurbished, as they are cheaper) are often used for packaging the NORM sands however in jurisdictions such as Australia where no disposal option exists the material tends to be stored until a future option becomes available. This practice can be viewed as speculative accumulation, which is not permitted in many other parts of the world.

Figure 2 Corrosion of steel drum containing TENORM

Offshore platforms and floating production storage and offtake (FPSO) vessels require extensive corrosion prevention and maintenance programs due to the seawater affecting all parts of the installations. This prevention and maintenance schedule rarely includes the steel drums that are stored on deck, and as such, the drums rapidly deteriorates into a non-compliant condition for transport and can be generally unsafe.

The drum in Figure 2 was lined with HDPE drum liners in addition to the material itself being put into 10 kgs sealed bags. The corrosion evident in the photo is suspected to be caused by seawater eventually penetrating the steel drum paint, and once the rust formed, it opened the pathway for seawater further, and the corrosion formed more rapidly. This was the case for over 60 of the approximately 120 drums inspected at this facility.

A proper storage container for 5 years should ideally resemble ISO tanks for chemical storage and transport. The upfront costs involved in either renting or purchasing these tanks and the handling equipment required to move them makes them a rarely used option on platforms with limited deck space and no forklift available.

It is the lower cost, easier handling and more flexible storage options of 205L drums over 4000L ISO tanks that drive the decision to use drums, and the lack of local disposal options that makes the storage of the material in those drums far longer than the drums can be expected to remain intact.

By using the transport code in isolation, at the time of handling this TENORM, the packaged material was in a condition that would have satisfied the requirements of SSR-6 for a Type IP-1 package.

RSO training

The level of competency that radiation safety officers have also greatly affects the decision-making process when transporting radioactive material or interpreting the requirements of transport codes.

In a jurisdiction without a functioning nuclear industry, little or no formal qualifications may be available, and the career options for a Health Physicist may be non-existent. A person looking to become a user of non-nuclear radioactive sources and devices may have to rely on short courses (1-3 days) that are developed specifically for licence holding.

In Australi, these licences to use radioactive sources restrict what a person can do (transport, dental, medical, portable XRF etc.) however do not specifically change the title. A person who has completed a one-day course to be the RSO of a contract carrier of radioactive material (*man-in-a-van* scenario) will have the same *RSO* title as a person who is the responsible RSO of a uranium mine. As such, when a person presents themselves as an RSO, this is not a specific role but role on a spectrum of risk management & competency.

As demonstrated previously, the radiological risk assessment for the transport of LSA and SCO type material only considers a small subset of the radiological risk the contents within a consigned package. A licence holder with one day of training and no technical qualification in radiation, occupational hygiene or health physics is unlikely to assess a materials risk beyond it being exempt material or not.

Conclusion

SSR-6 is a thorough set of requirements for the packaging and transport of radioactive material that encompasses the highest risk sources such as spent fuel casks down to benign soils samples with slightly elevated levels of naturally occurring isotopes. Importantly it defines a point, concentration and quantity, at which a material is a radioactive material, and that recognised definition among member states providing a high-level of consistency across jurisdictions.

The purpose of SSR-6 is not to determine the radiological risk to workers, members of the public and the environment of materials that both meet the exempt requirements but still have a potential radiological hazard.

A competent operator will recognise that the radiological risk of LSA or SCO type material and it being exempt as a non-radioactive source are not the same and further assessment by someone with formal qualifications, health physicist etc., is required.

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